MD Beltsville ARS

APB/TRD/BM/RG 3/27/95

Stream Restoration

Lower Cross Section

W/D Ratio = 18.3
Entrenchment Ratio = 1.4
Slope = .02 (Water Surface)
Sinuosity = 106/76 = 1.4
n = .039
Class B4 / G4

Middle Cross Section

W/D Ratio = 11.8
Entrenchment Ratio = 1.3
Slope = .013 (Water Surface)
Sinuosity = 1.03
n = .04
Class G5 / B5

Upper Cross Section

W/D Ratio = 10.8
Entrenchment Ratio = 2.5
Slope = .014 (Water Surface)
Sinuosity = 1.5
n = .032
Class E5

D.A. = 180 ac = 0.28 mi^2

MD Bellsville ABS

Q_{BF} Lower

D_{50} = Gravel ⇒ n = .039 from chart

$= \frac{1.49}{n} r^{2/3} S^{1/2} A$

$r = \frac{a}{p} = \frac{6.6}{11} = .6$

A = mean depth x width

$= \left(\frac{1.49}{.039}\right)(.6)^{2/3}(.02)^{1/2}(6.6)$

width

r = area/BF width

$Q_{BF} = 25$ cfs

Q_{BF} Middle

$Q_{BF} = \frac{1.49}{n} r^{2/3} S^{1/2} A$

$= \frac{1.49}{.04} (0.8)^{2/3} (.013)^{1/2} (7.78\ ft^2)$

$Q_{BF} = 29$ cfs

Q_{BF} Upper

$Q_{BF} = \frac{1.49}{.032} (.56)^{2/3} (.014)^{1/2} (7.89)$

n = .032
S = .014
a = 7.89
r = .56

Q_{BF} = 20 cfs (n = .047) Veg.
Q_{BF} = 30 cfs (n = .032) No Veg.

DESIGN TYPE B CHANNEL FROM 0+00 to 3+00

Parameters -

Entrenchment Ratio 1.4 - 2.2

Width/Depth Ratio > 12

Sinuosity > 1.2

Slope Range 0.02 - 0.039

$r_m = 2.9 \times BFW$

$L_m = 10-14 \times BFW$

$BFW = \sqrt{W/D \cdot A}$

Determine A_{BF} for B type (Fig. 11, C23)

$A_{BF} = 10\ ft^2$ for 30 cfs

$BFW = \sqrt{A \cdot W/D}$ choose W/D = 12 from above

$\therefore BFW = \sqrt{10 \times 12} = \underline{11.0\ ft}$

$W/D = 12 = \frac{11.0}{D_{mean}} \Rightarrow D_{mean} = \underline{0.92\ ft}$ $D_{MAX} = 1.5\ ft$ (from cross section for $A = 10\ ft^2$)

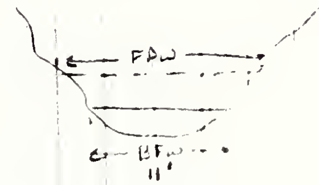
Meander Width Ratio (MW Ratio) = $\frac{\text{Beltwidth}}{\text{BFW}}$

Assume MW Ratio = 2 (Catina C 43 - Fig. 2) low end limited space minimize excav.

$2 = \frac{\text{Beltwidth}}{11.0} \Rightarrow \text{Beltwidth} = \underline{22\ ft}$ ok

BELTSVILLE ARS

Determine Flood Prone Width = Entr. Ratio x BFW



Current FPW = 15.5 ft (6 type)

Low Entr. Ratio - 1.4
FPW = 1.4 (11.0) = 15.4 = current - try larger

Try Entr. Ratio = 2.0
FPW = 2.0 (11.0) = 22 ft ok

can increase to 2.4 x 11.0 = <u>26.5 ft</u> FPW No, too much excavation

Use Entr. Ratio = <u>2.0</u>

Mean Radius of Curvature = r_m = 2.9 x BFW
= 2.9 x 11 = <u>32</u> ft.

Determine Meander Length = L_m = 10 - 14 x BFW

Plotting r_m = 32
$L_m \cong \frac{98 \text{ ft}}{BFW} = \frac{98}{11} = 9$ < 10 ok?

Sinuosity = $\frac{105}{98}$ = 1.1 ok

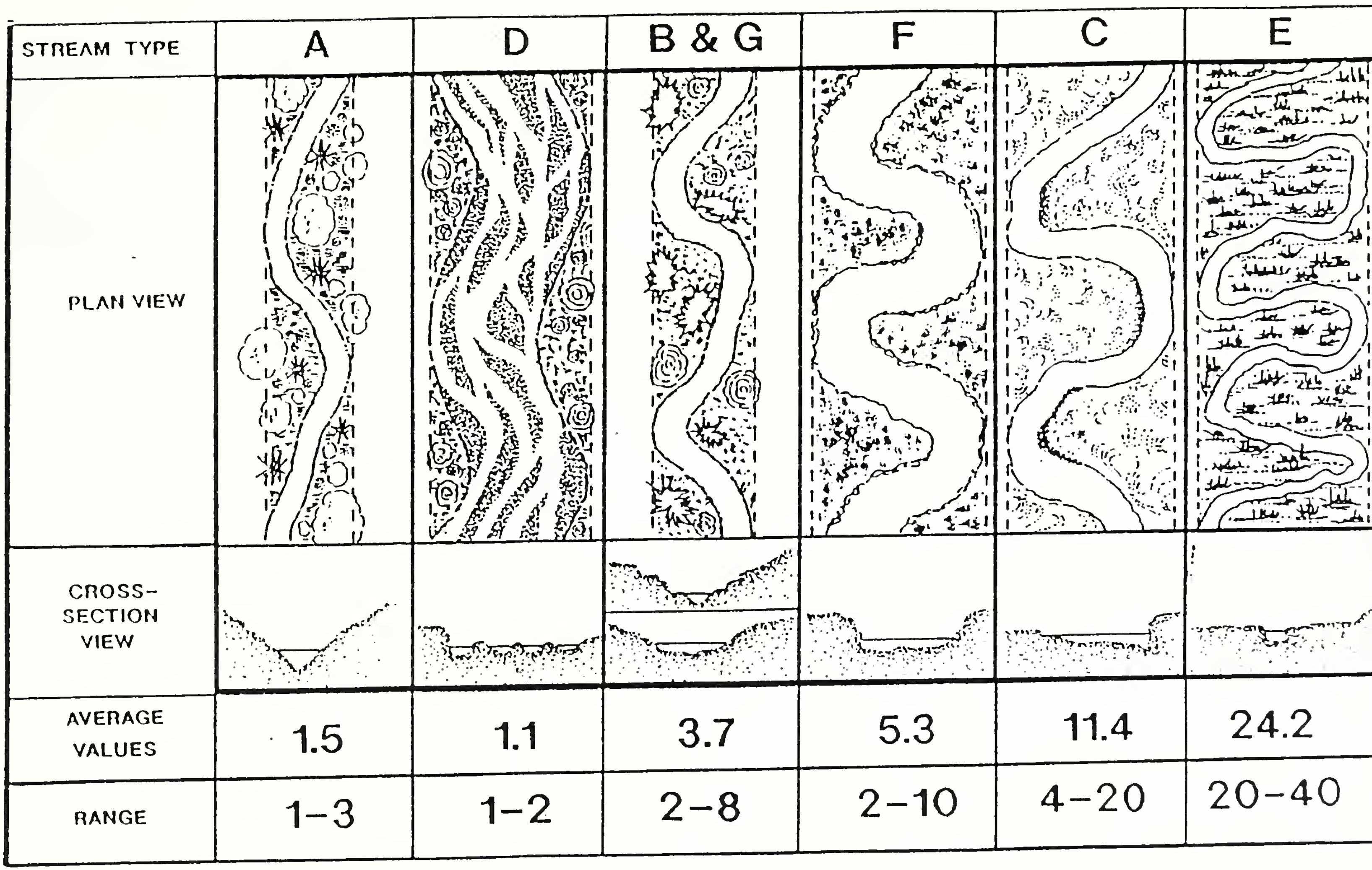
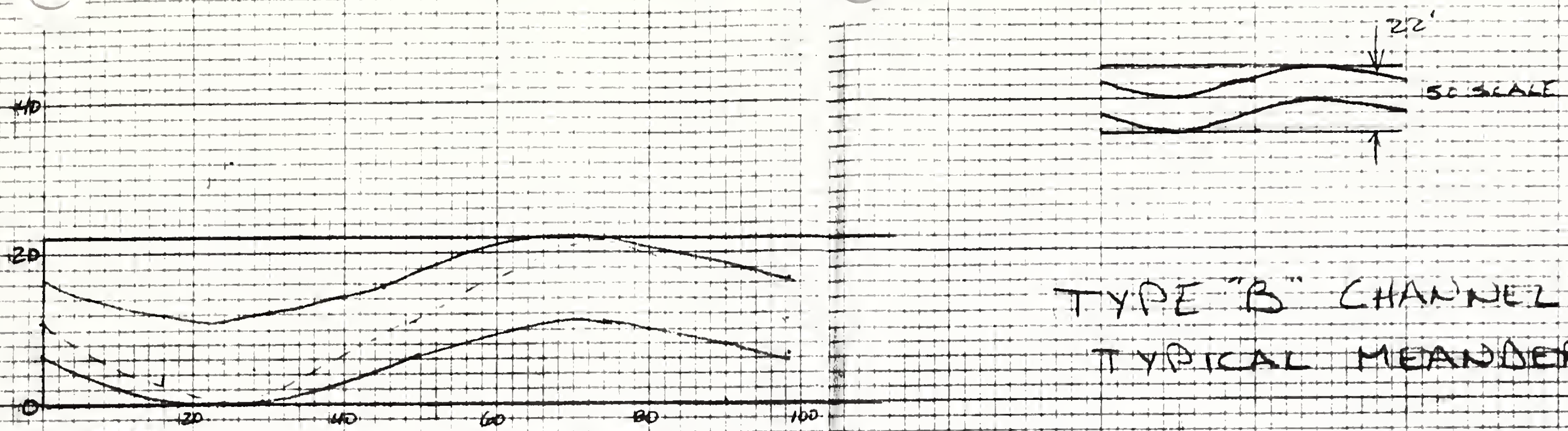
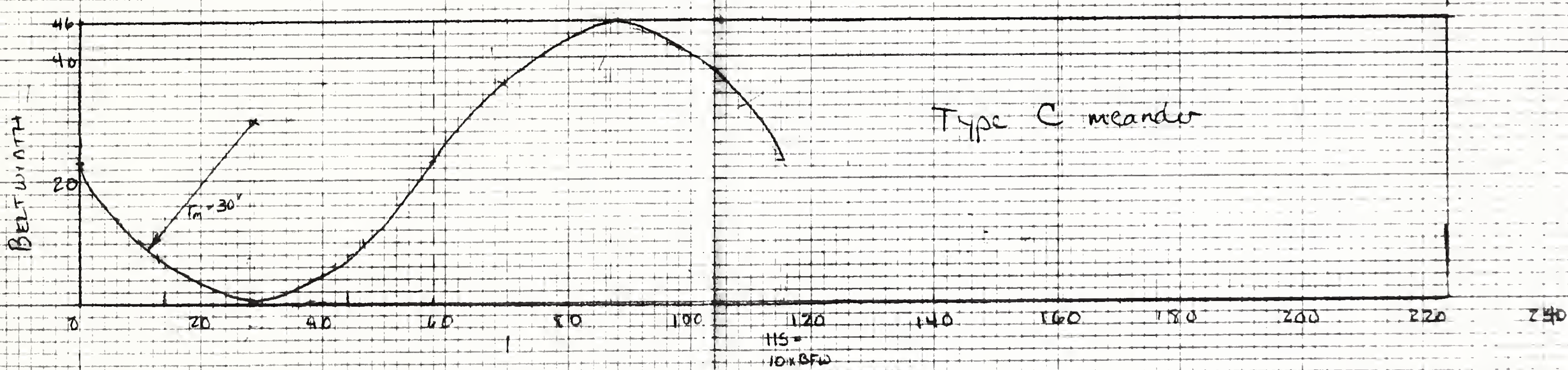


Figure 2. Meander width ratio (belt width/bankfull width) by stream type categories.



TYPE "B" CHANNEL
TYPICAL MEANDER



Type C meander

1" = 20' V/H

STA 3+00 to 12+85

ARS STREAM RESTORATION

MEANDER LENGTH

RADIUS OF CURVATURE

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Designed
Drawn
Traced
Checked

VORTEX ROCK WEIR INSTALLATION

NOTE: Vortex Rock weirs should be installed at the top and bottom of each meander bend. Boulders should be 16" to 24" diameter, minimum. The top of the footer rocks sets the design elevation for the stream invert.

1. Excavate the trench for the Vortex Rock Weir, such that the top of the footer rocks are at the design elevation of the stream invert. Place the footer rocks in the trench with as little space as possible between rocks.

2. Place the upper weir rocks slightly in front of the footers, so that at least 2/3 of the rock diameter will be buried below the elevation of the stream invert. The spacing between upper weir rocks should be as close to 1/2 the diameter (D) of the rocks. The arc of the weir should be such that there is a distance of approximately 2.5D between the leading edges of the upstream-most and downstream-most rocks. The top of the upstream-most rock should be at 15% - 20% of the bankfull elevation, and the top of the outermost rocks on each side should be at the design bankfull elevation. The tops of intermediate rocks should be on an even slope between the leading and edge rocks.

3. Backfill around upper weir rocks with natural bed material. Excavate scour pools a distance of 3-4D upstream and downstream of the weir, leaving at least 2/3 of the footer rocks below grade in the downstream scour zone.

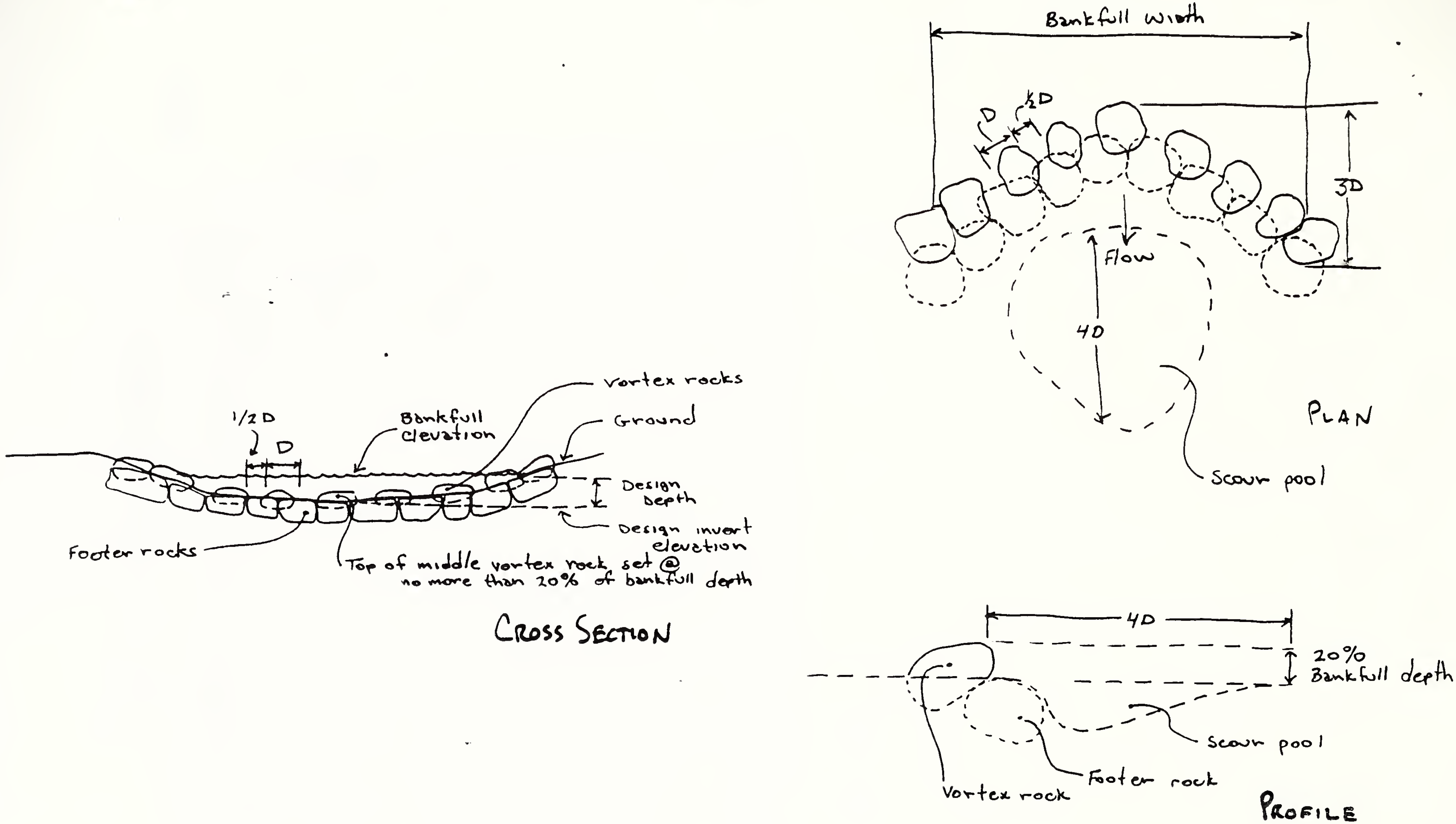


Figure 5. Vortex Rock Weir. Typical (NOT TO SCALE).

SHRUBS FOR SOIL BIOENGINEERING
(Northeastern United States and Canada)

SPECIES	COMMON	CULTIVAR
PRIMARY		
Salix purpurea*	basket willow	Streamco
Salix x cottetii*	dwarf willow	Bankers
Salix exigua*	sandbar willow	Greenbank
Cornus stolonifera*	redosier dogwood	Ruby
Cornus amomum*	silky dogwood	Indigo
Cornus racemosa	gray dogwood	
SECONDARY		
Alnus spp.	alder	
Amorpha fruticosa*	indigobush	
Baccharis halimifolia*	eastern baccharis	
Cephalanthus occiden.*	buttonbush	Keystone
Chamaedaphne calyc.	leatherleaf	
Forsythia sp.*	forsythia (most are hybrids)	many
Ilex verticillata	winterberry	
Physocarpus opulifol.	ninebark	
Prunus pumila var. depressa	dwarf sand cherry	Catskill
Salix bebbiana*	bebb willow	
Salix discolor*	pussy willow	
Salix humilis*	upland/gray willow	
Salix lucida*	shining willow	
Salix sericea*	silky willow	
Sambucus canadensis*	elderberry	
Viburnum dentatum	arrowwood vib.	
Viburnum trilobum	Am. cranberrybush	

*roots well from dormant hardwood cuttings

Northeast Shrubs Suitable for Soil Bioengineering Systems

Species	Habitat [1]	Bank Zone [2]	Root Form [3]	Shade Tolerance [4]	Flood Tolerance [5]	pH range [6]	Comments
Alnus serrulata **Smooth alder**	nontidal	toe	rooted	medium	regular	5.5-7.5	Nitrogen fixer weak wooded
Amorpha fruitcosa **False indigo**	nontidal tidal fresh	lower-mid	rooted unrooted	low	seasonal	5.0-8.5	Req. full sun Drought tolerant
Aronia arbutifolia **Red chokeberry**	nontidal	lower-mid	rooted	medium	irregular seasonal	5.1-6.5	Drought tolerant
Aronia melanocarpa **Black chokeberry**	nontidal	mid-upper	rooted	low	irregular seasonal	5.1-6.5	Drought tolerant
Baccharis halimifolia **Groundsel bush**	tidal tidal fresh	mid-upper	rooted, unrooted	high	seasonal	7.0-8.5	M/F separate plants
Cephalanthus occidentalis **Buttonbush**	nontidal tidal fresh	toe	rooted unrooted	high	permanent	6.0-8.5	Tolerates brief drought.
Celthra alnifolia **Sweet pepperbush**	tidal nontidal	mid-upper	rooted	high	seasonal	4.5-6.5	Some salinity & drought tolerance
Cornus amomum **'Indigo' silky dogwood**	streambanks pond edges	lower-mid	rooted unrooted	medium	seasonal	5.5-8.5	Drought tolerant
Cornus racemosa **Gray dogwood**	streambanks pond edges	lower-mid	rooted unrooted	high	seasonal	5.5-8.5	Drought tolerant
Cornus serecia **'Ruby' redosier dogwood**	streambanks pond edges	toe-mid	rooted unrooted	medium	regular seasonal	5.5-8.5	Drought tolerant

Northeast Shrubs Suitable for Soil Bioengineering Systems

Species	Habitat [1]	Bank Zone [2]	Root Form [3]	Shade Tolerance [4]	Flood Tolerance [5]	pH range [6]	Comments
Ilex decidua **Possumhaw**	forested wetlands pond edges	lower-mid	rooted unrooted	high	irregular	4.0-6.0	M/F separate plants
Ilex glabra **Inkberry**	forested wetlands sandy woods	mid-upper	rooted	high	irregular inundation	4.5-6.0	M/F separate plants. Resists salt spray
Ilex verticulata **Winterberry holly**	tidal fresh for.wetland	lower-mid	rooted	high	seasonal	4.5-8.0	Drought tolerant
Itea virginica **Virginia sweetspire**	forested wetlands streambanks	toe	rooted	high	regular	5.0-7.0	Tolerates some salt
Iva frutescens **Hightide bush**	tidal brackish	lower	rooted	low	regular	6.0-7.5	Tolerates 15ppt salt
Leucothe racemosa **Leucothe**	for wetland miost woods	lower mid	rooted	high	regular	5.0-6.0	Tolerates some dry-down
Lindera benzoin **Spicebush**	seasonal wetlands floodplain	lower-mid	rooted	high	seasonal	4.5-6.5	Tolerates some drought
Lyonia ligustrina **Maleberry**	open woods	lower-mid	rooted	low	seasonal	4.0-6.0	Acid tolerant
Magnolia virginiana **Sweetbay magnolia**	stream borders for.wetland	lower-mid	rooted	high	irregular/ seasonal	4.0-6.5	Tolerates infreq. flooding by salt
Myrica cerifera **Wax myrtle**	tidal fresh brackish swales	mid-upper	rooted	high	regular	4.0-6.0	Tolerates 10 ppt salt. N-fixing

Northeast Shrubs Suitable for Soil Bioengineering Systems

Species	Habitat [1]	Bank Zone [2]	Root Form [3]	Shade Tolerance [4]	Flood [5] Tolerance	pH range [6]	Comments
Myrica pennsylvanica **Bayberry**	tidal fresh brackish nontidal	mid-upper	rooted	high	irregular-seasonal	5.0-6.5	Tolerates drought. N-fixing
Physocarpus opulifolius **Ninebark**	streamsides wood edges	low-mid	rooted	medium	seasonal		
Prunus pumila var. depressa **'Catskill' dwarf sand cherry**	streamsides sandbars	mid-upper	rooted	low	irregular seasonal	5.5-8.5	Native to Del. River north Drought tolerance
Rhododendron viscosum **Swamp azalea**	forested wetlands	toe-low	rooted	medium	seasonal-regular	4.0-6.0	Susceptible to disease
Rosa palustris **Swamp rose**	tidal fresh for.wetland streambank	toe-low	rooted	low	seasonal-regular		Prefers full sun
Rhus typhina/glabra **Staghorn/Smooth sumac**	disturbed banks/dry sites	upper	rooted	low	irregular	6.1-7.0	Tolerates some drought
Salix X cottetii **'Bankers' dwarf willow**	streambank	toe-mid	unrooted rooted	medium	regular-permanent	5.0-7.5	Introduced male hybrid. Noninvasive
Salix discolor **Pussy willow**	streambank for.wetland	toe-mid	unrooted rooted	medium	regular-permanent	5.0-7.5	Attractive landscaping plant.
Salix exigua **'Greenbank' sandbar willow**	streambank sandbars	toe	unrooted rooted	low	regular-permanent	5.0-7.5	Aggressive root suckering Some salt tol.

Northeast Shrubs Suitable for Soil Bioengineering Systems

Species	Habitat [1]	Bank Zone [2]	Root Form [3]	Shade Tolerance [4]	Flood Tolerance [5]	pH range [6]	Comments
Salix purpurea **'Streamco' purpleosier willow**	streambank	toe-upper	unrooted rooted	medium	regular-permanent	6.0-7.0	Introduced noninvasive shrub
Sambucus canadensis **Elderberry**	tidal fresh nontidal wet meadow	low-mid	rooted-untooted	high	irregular-seasonal	5.5-8.0	Some salt tolerance drought tol.
Spirea alba/tomentosa **Meadowsweet**	for.wetland	mid-upper	rooted	low	irregular	5.1-6.0	
Viburnum dentatum **Southern arrowwood**	tidal fresh nontidal for.wetland	mid-upper	rooted unrooted	medium	seasonal	5.1-7.0	Tolerates drought
Viburnum lentago **Nannyberry**	for.wetland	mid-upper	rooted unrooted	medium	seasonal	6.0-7.0	Forms dense tickets
Viburnum prunifolium **Blackhaw viburnum**	for.wetland	upper	rooted unrooted	medium	irregular	6.5-7.0	
Viburnum trilobum **Am. cranberrybush**	for.wetland	lower-mid	rooted unrooted	low	irregular-seasonal	5.5-7.5	Tolerates drought[123456]

---

[1] Habitat: The natural community in which the plant is found.

[2] Bank Zone: Recommended planting location on the bank slope.

[3] Root Form: Rooted- a bare root (1-0 or 2-0) seedling or containerized.
Unrooted- a dormant hardwood cutting.

[4] Shade Tolerance: The relative value in relation to other species. A shade tolerant species may prefer partial shade to full sun.

[5]Flood Tolerance: **Semipermanently to permanently**: tolerates inundation or saturation from 76%-100% of the growing season.

Regularly: tolerates inundation or saturation from 26%-75% of the growing season.

Seasonally: tolerates inundation or saturation from 13%-25% of the growing season.

Irregularly: tolerates inundation or saturation from 5%-12% of the growing season.

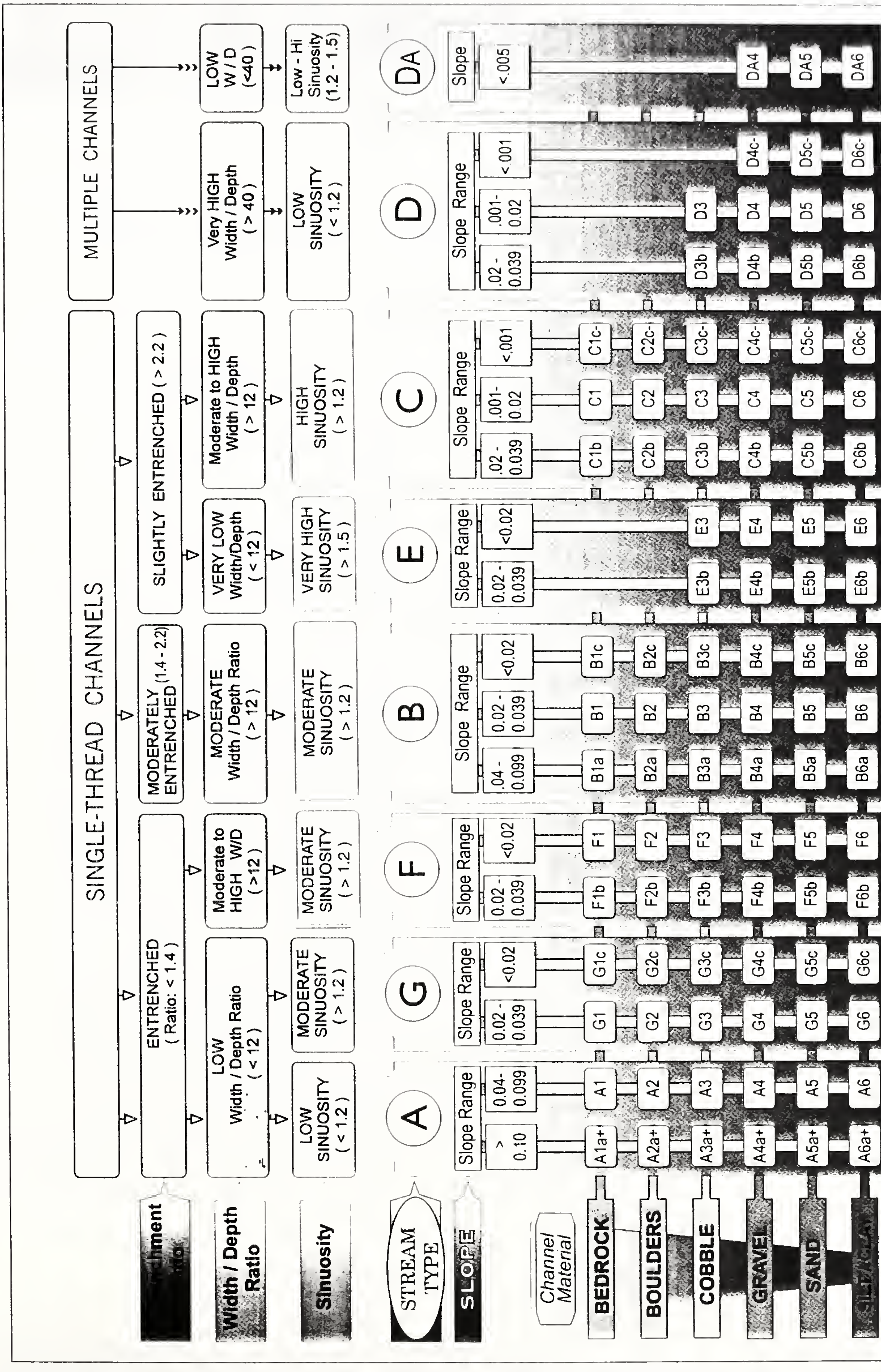
[6]pH range: Tolerance range of soil acidity.

TYPES AND CAUSES OF EROSION	
Type of Erosion	**Causes**
Toe erosion and upper bank failure	Removal of unconsolidated or noncohesive lower soil materials, especially along outside stream bends. Widespread toe erosion and upper bank failure may be associated with bed lowering.
General bed degradation (Bed scour over extended reaches)	Changes in stream gradient due to factors such as lowering of stream base level due to lake or tailwater fluctuations, stream channelization or stream relocation. Increased stream discharge due to flow diversion or watershed changes such as urbanization.
Headcutting	In stream undergoing bed degradation, headcuts often develop at locations where more resistant materials out crop in the stream channel. Headcuts may develop at a stream mouth when base level is lowered suddenly due to dredging, erosion or draining of a lake.
Middle and upper general bank scour	Increased discharge resulting from watershed changes; increased flow velocities caused by reduction in channel roughness or increased gradients; removal or loss of bank vegetation.
Local streambank scour	Scour of local lenses or deposits of unconsolidated material; erosion by secondary currents caused by flow obstructions and obstructions and channel irregularities; loss of bank vegetation.
Local bed scour	Local bed scour may be caused by channel constrictions, flow obstructions such as debris dams or flow deflectors, or trapping of sediment in reservoirs or sediment traps. Some scour generally occurs below culverts.
Piping	Piping develops when fines are removed by water flowing laterally under the surface. Extensive piping develop requires 1) rapid infiltration, 2) steep hydraulic gradients, and 3) zones of concentrated flow. Piping may occur in stratified soils where vertical movement is restricted by sudden reduction in hydraulic conductivity between strata or where poorly compacted soil around buried pipes provides conduits for water movement.
Overbank runoff	Failure to provide adequate means of directing concentrated flows from overbank areas into the channel.

Prepared by: Robbin B. Sotir & Associates

STREAMBANK STABILIZATION MEASURES

EROSION PROCESS	PRACTICE
Toe Erosion and Upper Bank Failures	Live cribwall at toe. Rock toe with vegetation, fascines, brushmattress, etc on upper bank. Conventional riprap or revetment.
General Bank Erosion	Brushmattress Live fascine Live staking Joint planting Conventional vegetation
General Bed Degradation	Grade control structures. Runoff detention facilities. Conventional riprap or revetment.
Local Bank Scour	Eliminate problem and armor scour hole.
Local Bed Scour	Eliminate problem and armor scour hole.
Piping	Intercept and drain subsurface water to a stable outlet; or Riprap with bedding designed as a filter
Overbank Runoff	Intercept and divert runoff to stable outlet; or Branchpacking, live fascine or live staking; Conventional lined chute or pipe drop spillway.



KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the "*continuum of physical variables*" within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

FIGURE 5-3. Classification key for natural rivers.

FACT SHEET

RIPARIAN BUFFER SERIES

WYE RESEARCH & EDUCATION CENTER • P.O. BOX 169 • QUEENSTOWN, MD 21658
(410) 827-8056 • FAX (410) 827-9039

An Introduction to the Riparian Forest Buffer

The word **riparian** refers to anything connected with or immediately adjacent to the banks of a stream or other body of water. Streamside forests are riparian forests. These areas, encompassing the floodplain and a portion of the adjacent upslope area are quite complex ecosystems and their ability to function naturally is crucial to the protection of the water resources of the United States. A buffer, meanwhile, is an area managed to reduce the impacts of an adjacent land use.

A riparian forest buffer, therefore, encompasses the area from the stream bank in the floodplain to, and including, an area of trees, shrubs and herbaceous vegetation located upslope from the body of water. It is an area managed to reduce the impacts of an adjacent land use. The width of the buffer depends on the land-owner's objectives, specific site conditions and the condition of the waterway.

This buffer serves several important functions: it preserves the stream's natural characteristics, protects water quality, and improves habitat for plants and animals on land and in the water. Based upon much research, a forested riparian buffer achieves these results by being a complex working ecosystem that connects a stream system and a people-based system such as agriculture, housing or industry.

*A riparian buffer **traps and filters sediments,** nutrients and chemicals from surface runoff and shallow ground water.*

*A framework of tree roots **stabilizes the stream bank.***

*Microbes in organic forest soils **convert nitrate into nitrogen gas** through denitrification.*

*Shade keeps the water cooler and **moderates temperature fluctuation** thereby increasing the water's ability to hold oxygen and support life.*

*The velocity of the stream flow slows around fallen trees and branches in the stream or river bed, **creating favorable areas for fish.***

*Plant stems slow water velocity and root systems keep the soil porous so excess water is absorbed into the ground and **flooding potential reduced.***

*Birds, mammals, and other animals find the **food, cover, water and nesting sites** they need as well as **corridors** and pathways for movement between areas.*

*A riparian forest buffer **improves the biological diversity** of surrounding areas.*

*The capacity to hold large amounts of water allows percolation to deeper water aquifers, **replenishing groundwater supplies**.*

If we look at the riparian area in segments beginning at water's edge and moving away or up slope a picture develops referred to as the "Three-Zone Buffer Concept". This provides a framework for thinking about the establishment and maintenance of a long-term riparian forest buffer. The width of this buffer is site specific and dependent on the landowner's objectives.

The important structural components in Zone 1 (next to the water's edge) are a mixture of fast and slow growing native trees. If the stream is small, at maturity the tree canopy from both sides of the stream meet or nearly so. Zone 2 is designed for uses such as timber harvest (pulpwood or sawtimber), outdoor recreation, wildlife habitat or alternative forestry products (such as gensing, mushrooms, nuts, etc.). Livestock are excluded from this zone.

Dense grasses and/or forbs compose Zone 3. The vegetative growth must be managed to promote nutrient uptake and sediment filtering.

Used along with other conservation or best management practices a riparian forest buffer offers a range of environmental benefits to everyone living in the Chesapeake Bay watershed.

Developed by
Robert L. Tjaden
Regional Specialist, Natural Resources
and
Glenda M. Weber
Faculty Assistant
Natural Resource Management

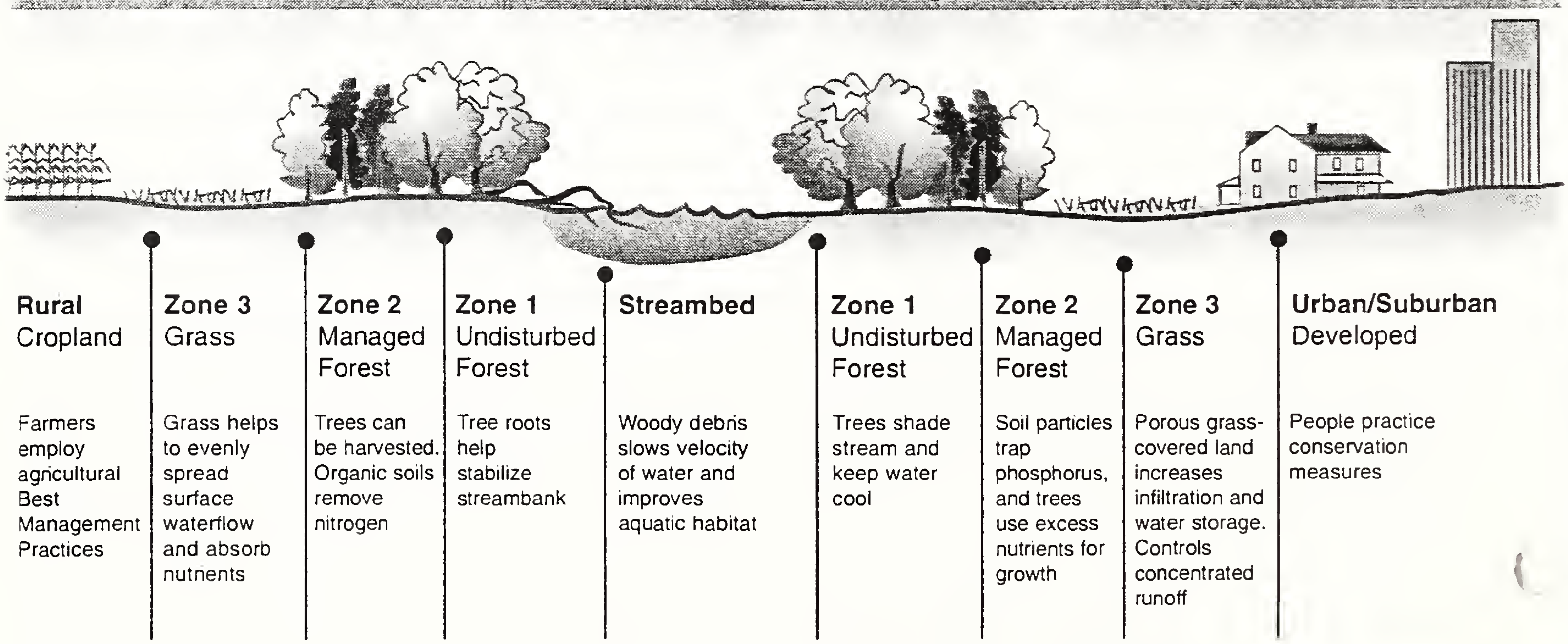
REFERENCES

Riparian Forest Buffers USDA-Forest Service 1996.

Alliance for the Chesapeake Bay White Paper: Riparian Forest Buffers, Jan. 1996.

The width of a riparian forest buffer is site specific and dependent on the landowner's objectives

The three-zone buffer concept provides a framework for the establishment and maintenance of a long-term riparian buffer.



COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF MARYLAND AT COLLEGE PARK
UNIVERSITY OF MARYLAND EASTERN SHORE

FACT SHEET
RIPARIAN BUFFER SERIES

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Buffer Design, Establishment and Maintenance

Design

Maintaining a forested buffer along creeks, streams and rivers provides more than just a beautiful landscape. The combination of trees, shrubs and native grasses can improve water quality by removing sediment and chemicals before they reach the waterway. A properly cared for buffer area also can moderate flooding, help recharge ground water, prevent soil erosion and preserve or improve certain types of wildlife habitat. Trees in the buffer strip also can provide landowners with valuable timber and alternative income sources, such as nuts, mushrooms, etc.

A well designed buffer system may include not only a multi-species buffer area established on land adjacent to the stream but also plantings that stabilize the streambank and wetlands constructed to absorb storm runoff.

This publication discusses how to design, plant and maintain a riparian forest buffer which is an important part of the riparian ecosystem. Much research supports the effectiveness of vegetative riparian buffers in improving water quality and related water issues. Of the various planting combinations that can be used in a vegetated riparian buffer a forested buffer is most effective when trying to obtain multiple resource benefits.

General Design

The most effective riparian buffers contain 3 different categories or zones of plantings as one moves away from the water's edge. Closest to the water is "zone 1," consisting of trees. The middle zone ("zone 2") can be trees with a combination of shrubs. Farthest from the stream and next to another land-use (for example crops, pasture or homes) is "zone 3." This zone is best planted with native grasses and forbs. The Three Zone Concept provides a framework for thinking about and grouping types of plantings. Combining fast and slow growing trees, shrubs and grasses/forbs helps protect the waterway better than a single species or one vegetational type, as well as providing a diverse habitat for wildlife. Trees and shrubs provide perennial, deep-reaching root systems to hold the soil and uptake nutrients into long-term storage in woody biomass. The forbs and grasses provide a high density of stems to slow surface runoff, trap sediment and uptake nutrients. Therefore, a riparian buffer functions to stabilize the soil, remove nutrients from both surface and sub-surface water flow, slow rainwater runoff velocity and trap sediments. These functions reduce the amount of non-point source pollutants entering our rivers and streams.

Zone 1

The trees in this zone are most important for streambank stability but also provide shade, deadwood and leaf litter inputs to the stream itself. This is very important to the health of the in-stream community and consequently the stream itself. Locally native riparian tree species are preferable since they coevolved with the stream inhabitants. Within this zone the tree species nearest the water's edge are selected for their ability to quickly develop deep roots that can increase bank stability. Bottomland species such as silver maple, black willow, eastern cottonwood, green ash and sycamore are best suited to these conditions in most locations throughout the Chesapeake Bay Watershed. These species tolerate wet conditions, grow fast and are brittle. The brittle habit allows the tree to shed branches during heavy flooding instead of washing away and exposing the banks to erosion, and regrow from the remaining trunk. In the drier portions of this zone hardwoods such as black walnut, red and white oak and white ash can be planted. If the water table is at least three feet below ground for most of the growing season, plant hardwood species that require good drainage. If the site has poor drainage, select hardwood species more tolerant of wet conditions. Some examples are river birch, black ash, bitternut hickory and hackberry. Table 1 lists other recommended species.

The large tree species mentioned above provide a canopy as they mature. Understory trees and shrubs should be interplanted among these canopy species to provide additional structure and shading next to the water. Table 2 lists shrub species tolerant of flooding and wet soils. Table 3 lists understory species recommended for the Chesapeake Bay watershed. On sunny banks, shade intolerant species will thrive until overshadowed by the canopy. On wide streams, southern and west facing banks receive more sun.

TABLE 1

Recommended Tree Species for Zones 1 & 2	
Willow oak	Basswood
Bald cypress	Hackberry
Black willow	Pitch pine
E. cottonwood	American beech
Red maple	Sweetgum
Swamp white oak	Black walnut
Blackgum	Bitternut hickory
Green ash	Persimmon
Silver maple	White ash
Sycamore	Tulip poplar
River birch	White oak
Loblolly pine	Red oak

TABLE 2

Recommended Shrub Species for Zones 1 & 2	
Buttonbush	Swamp leucothoe
Pussy willow	Pinxterbloom azalea
Sweet pepperbush	Bayberry
Swamp azalea	Silky dogwood
Winterberry	Common ninebark
Arrowwood	Red chokeberry
Highbush blueberry	Spicebush
Elderberry	Grey dogwood
Virginia sweetspire	Rosebay rhododendron
Inkberry	Mapleleaf viburnum

North-facing streambanks receive less solar exposure. Fewer species thrive in these shadier conditions so plant selection is

more limited. Swamp leucothoe (fetter-bush), pinxterbloom azalea, spicebush, rosebay rhododendron and mapleleaf viburnum are good choices.

TABLE 3

Recommended Understory Woody Plants for Zones 1 and 2	
Box elder	Shadblow
Common alder	Pawpaw
Sweet bay	Hornbeam
Black haw	Redbud
Possumhaw	Flowering dogwood
Witch hazel	Am Holly

Zone 1 is an undisturbed forest area where logging is generally not recommended. Livestock are excluded from this zone. Stream crossings, watering sites and any streambank stabilization work are carefully planned to minimize negative water quality impacts.

Zone 2

This zone provides necessary contact time between water borne nutrients/ pollutants and natural ecological systems for cleansing (buffering) processes to take place. This zone also provides long-term sequestering of nutrients in the woody biomass of trees and shrubs. To some extent it is an extension of zone 1. It is dominated by large trees with an understory of smaller trees and shrubs. This zone can tolerate some disturbance. Where site conditions permit, commercially viable species are planted for possible future logging. This zone provides a wide range of forest management options. Other non-traditional agricultural products can be grown in this area (for example Christmas trees, nut crops, shade-loving wildflowers, ginseng and others).

Select species adapted to the specific site soil conditions. Look at adjoining areas for the types of native species that grow in that locale. Shade tolerant shrub species such as winterberry, Virginia sweetspire and mapleleaf viburnum generally do well in this zone. By planting a variety of tree and shrub species diversity increases and wildlife habitat improves. Also, planting a mix of species prevents loss of benefits if one species does not thrive or fails to grow completely. In areas with heavy deer browsing, spicebush and mapleleaf viburnum are good choices (Tables 1, 2 and 3).

Zone 3

As the transition zone between the forested areas in zones 1 and 2 and adjacent land uses, zone 3 must be carefully designed. This zone functions to filter sediments, increase water absorption capacity, convert nutrients into green biomass, uptake nutrients and spread concentrated surface water flow to a uniform sheet flow, as well as providing valuable food and/or cover for certain wildlife species. A dense, herbaceous cover with no trees or shrubs works best to slow and filter runoff. After appropriate grading and shaping grasses are planted. Switchgrass is preferred because its dense, stiff stems remain upright throughout the seasons to slow the overland flow of water, allowing water to infiltrate and sediment carried by the water to be deposited in the buffer area. In addition, switchgrass produces an extensive and deep root system, much of which is replaced annually, providing large amounts of organic matter to the soil. Organic matter improves soil quality by increasing infiltration rates and microbial activity. Switchgrass does take approximately 3 years to become fully established.

Where surface runoff is not a major problem, other permanent grasses such as

Indiangrass, big bluestem and little bluestem can be used. Black-eyed Susan and purple- and gray-headed coneflower also might be planted with grass to intercept surface runoff that might occur. Other grasses may be combined with the switchgrass to promote wildlife diversity within this zone.

Native forbs (broad-leaved herbaceous plants/wildflowers) also may be part of the mix, especially if they are seeded in clumps with other native grasses. Cool-season grasses, such as brome and fescue, are not appropriate for zone 3 because they do not tend to remain upright under the flow of water and provide limited wildlife value. They also produce up to eight times less root mass than native grasses and, therefore, do not improve soil quality as quickly or as much as the same planting of warm-season grasses.

Other Planting Strategies

The combination of plantings already described provide the most effective buffer system, but the three zones are not the only approach to improving water quality, habitat and flood control. Site conditions, surrounding land use, owner objectives and cost-share program requirements should be considered in determining combinations of species for a buffer strip.

Following are other possibilities that provide some reduction of non-point source pollution.

- Plant the entire buffer area to warm-season grasses and forbs. Some soil stabilization may be needed such as growing willow stakes along the streambank. This system does not provide as many benefits as a multi-species design (3 zones) and is best suited where streambanks are not very high or steep.
- In urban areas, plant warm-season grasses over the entire area and small groups of shrubs and/or trees to provide a diverse, natural look. Recreational facilities such as hiking or bike trails can be incorporated into the system. Design with care to avoid erosion problems often associated with runoff from trails.
- Accelerate succession by overplanting with seedlings of fast growing shade intolerant species at a high enough density to provide canopy closure relatively rapidly. Tulip poplar, box elder and silver maple are among the fastest growing trees appropriate for the riparian zone. Seedlings of shade tolerant canopy species, such as red oak, interplanted among these pioneer species can be selectively released after canopy closure to become the eventual dominants. That is, once the species intended to be the dominant trees are well established the protective, fast-growing, shade intolerant species are removed. Canopy overplanting will also reduce deer browsing on the future dominant species. This release succession strategy also provides more wildlife habitat and deadwood in the riparian zone. The use of succession management strategies is largely determined by the existing vegetation in the riparian zone. Where many indigenous seedlings exist, the planting approach should attempt to capitalize on this.

Buffer Strip Width

There is no ideal buffer width for all applications in all areas. Many factors including slope, soil type, adjacent land uses, floodplain, vegetational type, watershed condition and others influence what can be and is planted. The function of the buffer, that is, the reason for installing a riparian buffer, should be the overriding

criteria with other factors such as listed above, influencing the final decision to a greater or lesser degree.

The most commonly prescribed minimum buffer widths for use in water quality and habitat maintenance are approximately 35 to 100 feet. Buffers of less than 35 feet cannot sustain long-term protection of aquatic resources. Figure 1 associates a range of buffer widths with some specific buffer benefits.

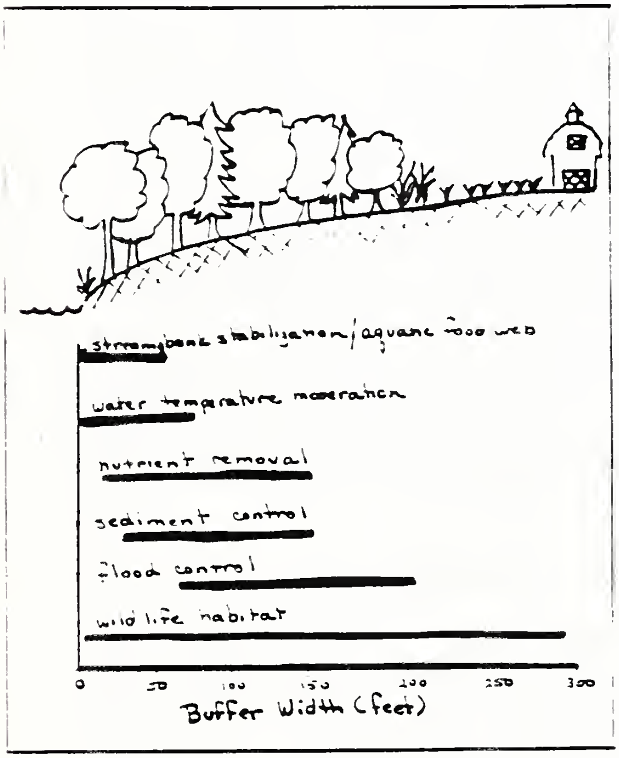

Figure 1 (adapted from Agroforestry Notes, Jan. 1997).

Site Preparation

Often, a riparian area will have a mixture of pasture, overgrown fields and a line of scrappy trees along the stream. This requires a combination of site preparation techniques. In all situations a combination of physical and herbicidal methods will be most effective and efficient. Site preparation should begin the fall prior to planting. In some situations site preparation can require up to a year of vegetative control prior to planting. Any necessary streambank stabilization needs to be included in the planting plan so work can proceed in a logical order.

If the area has been used for row crops, disk the ground in the spring and seed the area where the woody material will be planted with a cover crop such as annual or cereal rye. Since a good cover is essential, cool season grasses such as field bromegrass and tall fescue are often appropriate. These grasses are not invasive, do not require mowing and will be shaded out by the woody plants.

In pasture type situations eliminate competing perennial vegetation with herbicides in 3 ft wide to 4 ft wide circles or strips where trees or shrubs will be planted. Other problem species such as multiflora rose and honeysuckle will still need to be controlled by cutting, pulling and/or herbicides.

Abandoned fields of varying ages already have tree saplings, shrubs and vines. In this situation, site preparation focuses on releasing the desired saplings and other plants from competition by undesired species. Release methods vary according to the target species and extent of infestation by invasives. Techniques include basal bark spray herbicides during the dormant season, cutting large shrubs and vines then treating the stumps to prevent resprouting and mowing everything around the "keepers" after they have leafed out in late spring. Larger cut stumps may also require an application of an herbicide to control resprouting.

Plant Materials

One- to two-year-old seedlings of most tree and shrub species, or rooted or un-

rooted cuttings of willow can be obtained from various forest nurseries. Order plants early to get desired species and type of planting stock. Consider ordering 10 to 15 percent more trees and shrubs than what you think you will need. The additional plants can be planted in a nearby "holding" area and used for replacement plantings. Seeds should be ordered as PLS (Pure Live Seed) to ensure you are paying for and planting only live seed, not inert material.

Plant trees and shrubs as soon as possible after receiving them. If planting must be delayed, keep plants cool and moist. Always use high quality stock with good root systems. Quality hardwood seedlings should have a minimum of four to five large lateral roots.

Trees and shrubs should be planted in early spring. A tree planter, auger, planting bar or shovel can be used to plant seedlings and cuttings. Before planting, soak rooted cutting 2 to 4 hours in water and unrooted cuttings 24 hours. Root collars of seedlings should be slightly below the soil surface. Make sure planting holes are closed and the soil around the root or cutting is firm. For unrooted cuttings, plant deep enough to leave only 1-2 buds above ground.

Grass and forb seeds may be broadcast planted using a spinner-type seeder or a drop-seeder. Because of the light, fluffy nature of the seed, broadcast seeding of warm-season grasses can only by accomplished with clean seed. This means at least 75% PLS. Seed less than 75% PLS should be planted with a specialized warm-season grass drill or planter.

Plant trees 8-12 ft. apart. Depending on species and desired results, leave 8-12 ft. between trees in the row. Spacing will vary considerably depending on your objectives and species. The production of timber, biomass and wildlife all have different planting recommendations.

Maintenance

Weed control is essential for survival and rapid growth of trees and shrubs in a buffer strip. Options include 4-6 inches of organic mulch, weed control fabrics, shallow cultivation, preemergent herbicides and mowing. Non-chemical weed control techniques are preferred because chemicals can quickly enter the water system in riparian areas. Continue weed control until woody plants occupy the area, normally 2 to 3 years. For more information about weed control, contact your state service forester, or state extension forester.

During the first year, control annual weeds in zone 3 by mowing to 6 inches. Do not let weeds get higher than 12-14 inches before mowing. Cutting down tall weeds can smother the small seedlings below. During the second year mow to 12 to 18 inches in early summer if weeds are a problem. Mowing lower could harm plants and nesting animals.

Long-term Management

Buffer strips must be monitored and managed to maintain their maximum water quality and wildlife habitat improvement. They should be inspected at least once a year, and always within a few days of severe storms for evidence of sediment deposit, erosion, or concentrated flow channels. Repairs should be made as soon as possible.

Grasses should be harvested, burned, or in some instances, may be control grazed. The use of fast growing tree species ensures rapid growth and effective removal of nutrients and other excess chemicals that could pollute waterways. Harvesting fast-growing trees as early as possible removes the nutrients and chemicals stored

in their woody stems. Periodic harvesting also promotes continued vigorous growth. If harvested in winter, these species will regenerate from stump sprouts, thereby maintaining root system integrity and continued protection of the streambank.

Finally, if possible, avoid working in the riparian area between April 15th and August 15th. During this time period disturbance can be detrimental to a variety of wildlife.

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COOPERATIVE EXTENSION SERVICE UNIVERSITY OF MARYLAND AT COLLEGE PARK UNIVERSITY OF MARYLAND EASTERN SHORE

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Trees for Riparian Forest Buffers

Tree selection for a riparian forest buffer requires considering several factors. Trees closest to the waterway are most likely to be flooded, and need a greater tolerance to high water tables. If the area has recently been disturbed, trees with a fast growth rate will more quickly establish root systems to hold the soil. Fast-growing trees are not necessarily long-lived and interplanting fast and slower growing trees is a wise practice. Eventual tree height needs to be considered for at least three points (1) At its maximum height, will the tree provide adequate shade for the stream? (2) Are there any landowner aesthetic considerations (to either screen or frame a view, provide a windbreak)? (3) Are there safety considerations such as avoiding power and telephone lines, road view for traffic? Trees with shallow rooting systems hold surface soils well but do not provide as much stability to high banks and steep slopes as trees with deeper root systems. Also deeper root systems anchor trees better where there are repeated flooding/ drying cycles. Below is a list of trees recommended for Maryland compiled from several references. Information on their ecological and growing characteristics should help the landowner determine species suitable for a specific riparian forest buffer site.

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REFERENCES

Woody Plants of Maryland by R.G. Brown and M.L. Brown, 1972.
Chesapeake Bay Riparian Handbook, USDA - Forest Service, 1997.
Knowing Your Trees by G.H. Collingwood and W.D. Brush, 1984.

	Region	Wildlife Value	Light preference	Flood tolerance	Growth rate	Height	Rooting
	Coastal plain (CP) Piedmont (P) Mountains (M)	V. high High Medium Low	○ ◗ ●	High Average Low	V. fast Fast Medium Slow	>75' 50-75' <50'	
Bald cypress	CP, P	Low	○/◗	High	Medium	>75'	Shallow
Black willow	P, M	Medium High	○	High	V. fast	50-75'	Shallow
Eastern cottonwood	CP, P, M	Low	○	High	Fast	>75'	Deep lateral
Green ash	CP, P, M	Low	○	High	V. fast	50-75'	Shallow
River birch	CP, P, M	Cavity nesting low	○/◗	High	Fast	50' +	Shallow
Sweet gum	CP, P	Medium Low	○/◗	Medium	Medium	50-75'	Deep taproot
Sycamore	CP, P	Low	○/◗	Medium	V. fast	50-75'	Shallow
Bitternut hickory	CP, P	Medium	○/◗	Medium	Medium Slow	>75'	Deep taproot
Black walnut	P, M	Medium Low	○/◗	Low	Medium	>75'	Taproot
Blackgum	CP, P, M	Medium	○/◗	Medium High	Slow	50-75'	Taproot
Hackberry	CP, P, M	High V. high	○/◗	Medium	Fast Medium	>75'	Deep lateral
Persimmon	CP, P	V. high High	○	Medium	Slow	<50'	Deep taproot
Red maple	CP, P, M	Medium High	○/◗	Medium High	Fast Medium	50-75'	Very shallow

	Region	Wildlife Value	Light preference	Flood tolerance	Growth rate	Height	Rooting
White oak	CP, P, M	V. high	○/◗	Low Medium	Slow	> 75'	Deep taproot
Willow oak	CP, P	High	○/◗	Medium High	Fast Medium	> 75'	Shallow
Silver maple	CP, P, M	Low	○/◗	Medium	Medium	> 75'	V. shallow
Tulip tree	CP, P, M	Low	○/◗	Low	Fast	> 75'	Shallow
American holly	CP, P	High	◗	Limited Average Low	Slow	30-40'	Taproot
American hornbeam	CP, P, M	Medium High	◗/●	Medium High	Slow	30-40'	Deep lateral
Hemlock	P, M	Medium	○/◗/●	High	Slow	> 75'	Deep lateral
E. Red cedar	CP, P	Medium High	○/◗	Low	Slow	< 50'	Shallow
Dogwood	CP, M	Medium High	○/◗/●	Low	Slow	30-40'	Shallow
Hophornbeam	CP, P, M	Medium	○/◗/●	Low Medium	Slow	< 30'	Shallow
Water oak	CP	Medium	○/◗	Medium High	Fast	50-75'	Shallow
Cherrybark oak	CP	High	◗	Low	Medium	> 75'	Taproot
Black locust	P, M	Low	○	Low	Medium	50-75'	Shallow
Paw-paw	P	V. high	◗/●	Low	Slow	30-40'	Deep lateral
Sweet bay magnolia	CP, P	V. low Low	◗	Medium	Medium	< 30'	Deep lateral
Grey birch	CP, P	Medium	○	Low Medium	Fast	< 30'	Shallow
Crabapple	CP, P, M	High	○/◗	Low	Medium	< 30'	Shallow

	Region	Wildlife Value	Light preference	Flood tolerance	Growth rate	Height	Rooting
Sugar maple	M	Medium	○	Medium	Slow	<75'	Shallow
Sweet birch	M	Medium	○	Medium	Medium	50-75'	Shallow
Mulberry	CP, P	High	○	Medium	Fast	30-40'	Shallow
Sassafras	CP, P, M	High	○	Low	Fast	<50'	Shallow
Hawthorn	CP, P, M	High	○	Low Medium	Medium	<30'	Shallow
Shingle oak	CP, M	High	○/◗	Medium	Slow Medium	<50' 50-75'	Taproot
Swamp chestnut oak	CP, P	High	○	High	Slow	50-75'	Shallow
Loblolly pine	CP, P	Low Medium	○	Medium	Fast	>75'	Shallow
Pin oak	CP, P	High	○/◗	Medium High	Fast Medium	>75'	Shallow
White ash	P, M	Medium High	○/◗	Medium Low	Medium	>75'	Shallow
Box elder	P, M	Low Medium	○	Medium High	V. fast	>50'	Deep lateral
American beech	CP, P	High	◗/●	Low	Medium Slow	>75'	Shallow
Black cherry	CP, P, M	High	○/◗	Low	Medium	<50' 50-75'	Deep taproot
Chestnut oak	P, M	High	◗	Low	Slow	50-75'	Taproot Deep lateral
Choke cherry	CP, P, M	High	○/◗	Low	Fast	<50'	Deep taproot
Larch	M	Low	○	High	Medium Fast	50-75'	Shallow

	Region	Wildlife Value	Light preference	Flood tolerance	Growth rate	Height	Rooting
Scarlet oak	CP, P, M	High	○	Low	Fast	50-75'	Shallow
Shadblow	P, M	High	◗/●	High	Slow	30-40'	Shallow
Swamp oak	CP, P	High	○/◗	High	Slow	50-75'	Shallow
Swamp white cedar	CP	Medium	○	Medium	Medium Slow	50-75'	Shallow
Swamp white oak	CP, P	High	○/◗/●	Medium High	Fast Medium	50-75' >75'	Shallow
Pitch pine	CP	Low	○	Low	Medium Slow	<50'	Shallow
Southern red oak	CP, P, M	Medium	○/◗	Low Medium	Medium	50-75'	Deep lateral
Northern red oak	CP, P, M	Medium	○/◗	Low Medium	Medium	>75'	Deep lateral
Red bay	CP	Medium	◗	High	Slow	<50'	Shallow
Overcup oak	CP	High		Medium High	Slow	50-75'	Shallow
Swamp chestnut oak	P, CP	High	◗	Low High	Slow	50-75'	Shallow
American Basswood	P, M	Low	○/●	Medium	Medium	>75'	Deep lateral

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Understory Plants for Riparian Forest Buffers

The following lists contain understory tree species and shrubs appropriate for riparian forest buffers. Understory tree shrubs are tolerant to shade and are an important structural component of any forest. Some shrubs such as rhododendron and some blueberries are also adapted to the low light conditions of the forest understory but more are adapted to an edge situation. The edge may be either next to the water or next to an upland area. Most of the shrubs listed prefer moist growing conditions and are good choices for areas that filter waterflow. Shrubs that prefer drier sites include witch hazel, grey dogwood and rosebay rhododendron.

By including understory trees and shrubs in a riparian forest buffer planting the structural diversity of the buffer increases. This promotes an increased biodiversity and enhances both water quality and wildlife habitat attractiveness of the buffer.

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REFERENCE

Chesapeake Bay Riparian Handbook, USDA-Forest Service, 1997.

Educating People To Help Themselves

Riparian Shrub List

		Wildlife Value	Light Preference	Flood Tolerance	Growth Rate	Deciduous/ Evergreen	Rooting
	Coastal plain (CP) Piedmont (P) Mountains (M)	V. high High Medium Low	○ ◗ ●	High Average Low	V. fast Fast Medium Slow		
Smooth alder	All	Medium	○	High	Fast	Deciduous	Shallow
Black Haw	All	High	○ → ◗	High	Medium	Deciduous	Shallow
Possumhaw	CP	High	○ → ◗	High	Medium	Deciduous	Shallow
Witch hazel	P, M	Med → Low	○ → ◗	Low	Medium	Deciduous	Deep lateral
Button bush	All	Med High Low	○ → ◗	High	Medium	Deciduous	Shallow
Pussy willow	P, M	High Medium	○	High Medium	Fast	Deciduous	Shallow
Sweet pepper bush	CP, P	Medium HIGH	○ → ◗	High Medium	Medium Slow	Deciduous	Shallow
Swamp azalea	CP, P	Low	○ → ◗	High	Medium	Deciduous	Shallow
Winterberry	CP, P	High	○ → ◗	High	Slow	Deciduous	Shallow (seasonally flooded areas)
Arrowwood vib.	All	Low High	○ → ◗	Average	Medium	Deciduous	Shallow
Highbush blueberry	CP, P	V. high	○ → ◗	High	Slow	Deciduous	Shallow
Elderberry	All	V. high	○ → ● ○ → ◗	High	Fast	Deciduous	Shallow
Virginia sweetspire	CP	Low	○ → ◗	High	Medium Slow	Deciduous	Shallow
Inkberry	CP	High	○ → ◗	High	Slow	Evergreen	Shallow

		Wildlife Value	Light Preference	Flood Tolerance	Growth Rate	Deciduous/ Evergreen	Rooting
Swamp leucothoe	CP, P	Low	◗ → ●	Average	Slow	Evergreen	Shallow
Pinxterbloom azalea	CP, P	Low	◗ → ●	High	Slow	Deciduous	Shallow
Bayberry	CP	High	○	High	Medium	Deciduous/ Evergreen	Shallow
Silky dogwood	P, M	High	○ → ◗ ◗ → ●	Average	Fast	Deciduous	Shallow (good bank stabilizer)
Common ninebark	CP, P	Medium	○	High	Fast	Deciduous	Shallow
Red chokeberry	CP	Medium	○ → ◗	High	Slow	Deciduous	Shallow
Spicebush	All	V. high	● → ◗	Average	Slow	Deciduous	Deep lateral
Grey dogwood	P, M	V. high Medium	○ → ◗	Average Low	Medium	Deciduous	Shallow
Rosebay rhododendron	All	Low	● → ◗	Low	Slow	Evergreen	Shallow
Mapleleaf viburnum	All	High	◗ → ●	Low	Medium Slow	Deciduous	Shallow
Smooth alder		High				Deciduous	Shallow (rapid growth, stabilizes streambanks)
Red osier dogwood	All	High	○ → ◗	High	Fast	Deciduous	Shallow
Speckled alder	M	Medium	○	High	Fast	Deciduous	Shallow

Riparian Understory Trees List

	Region	Wildlife Value	Light preference	Flood tolerance	Growth rate	Height	Rooting
	Coastal plain (CP) Piedmont (P) Mountains (M)	**V. high High Medium Low**	○ ◗ ●	**High Average Low**	**V. fast Fast Medium Slow**	**>75' 50-75' <50'**	
American holly	CP, P	High	◗	Limited Average Low	Slow	30-40'	Taproot
American hornbeam	CP, P, M	Medium High	◗/●	Medium High	Slow	30-40'	Deep lateral
Dogwood	CP, M	Medium High	○/◗/●	Low	Slow	30-40'	Shallow
Hophornbeam	CP, P, M	Medium	○/◗/●	Low Medium	Slow	<30'	Shallow
Paw-paw	P	V. high	◗/●	Low	Slow	30-40'	Deep lateral
Sweet bay magnolia	CP, P	V. low Low	◗	Medium	Medium	<30'	Deep lateral
Sassafras	CP, P, M	High	○	Low	Fast	<50'	Shallow
Persimmon	CP, P	V. high High	○	Medium	Slow	<50'	Deep taproot
Hawthron	CP, P, M	High	○	Low Medium	Medium	<30'	Shallow
Box elder	P, M	Low Medium	○	Medium High	V. fast	>50'	Deep lateral
Shadblow	P, M	High	◗/●	High	Slow	30-40'	Shallow
Red bay	CP	Medium	◗	High	Slow	<50'	Shallow

East Region Supplement No. 1,

Engineering Field Handbook, Chapter 16 Guidelines for Planning and Designing Streambank and Shoreline Protection Projects

September, 1997

Purpose

These guidelines are a companion to complement and further explain information contained in USDA-NRCS Engineering Field Handbook (EFH), Chapter 16, *Streambank and Shoreline Protection* and Field Office Technical Guide Section IV, *Standard for Streambank and Shoreline Protection-580.* Its focus is to offer a logical sequence to determine the possibilities of integrating soil bioengineering techniques with traditional streambank and shoreline stabilization solutions.

Introduction

Using soil bioengineering techniques with conventional engineering has gained increased acceptance since the early 1990's. Numerous projects have been installed throughout the Northeast. To assist in planning these treatments the NRCS has revised Chapter 16 and prepared a new Chapter 18 of the EFH. Although these documents provide valuable planning information, they do not adequately address the engineering and geomorphic processes needed to insure successful soil bioengineering projects. In addition, they do not provide guidelines for selecting soil bioengineering techniques.

Planning

Soil bioengineering is not appropriate for all situations, but should always be considered as an alternative. The Soil Bioengineering Application Chart (Figure 1) can be used to determine if soil bioengineering techniques are appropriate for correcting existing erosion problems or for preventing future erosion of shorelines or streambanks. Determination of Hazard Class for Streambank and Shoreline Protection (Figure 2) can be used to estimate the level of design needed. Soil bioengineering techniques may be used singularly or in combination with one another or in combination with other erosion control techniques, such as rock riprap bank protection or timber cribwalls. The National Planning Procedures Handbook presents the most comprehensive list of factors to be evaluated when planning a project. As a minimum, the following conditions should be evaluated to help ensure a proper soil bioengineering design:

* Soil type (as classified by USDA & USCS) and moisture availability
* Slope stability based on specific soil conditions
* Surface runoff (a diversion or lined waterway may be necessary to ensure success)
* Available quantity and quality of materials for soil bioengineering
* Stream classification and channel equilibrium. Determine elevation of bank forming (bank full) discharge
* Effects of mature vegetation on stream hydraulics, including upstream and downstream of the treatment area
* Time of year for installation (unrooted woody vegetation must be installed during the dormant season)
* Access to streambanks (hard surfaced areas may be necessary to provide access for recreation visitors)
* Evaluation of historic and proposed

land use changes in the watershed which may impact or create erosion

- Long term maintenance requirements
- The amount of exposure to sunlight (soil bioengineering projects succeed best in full sun)

DESIGN

Geomorphic Processes

A stream classification based on natural streams in the western U.S. has been developed by David Rosgen. It is an important improvement and valuable tool in understanding stream processes, however, it's applicability as a design tool is limited in the East Region because all our streams and watersheds are continually manipulated by changing land use. Determining if a channel system is in equilibrium or disequilibrium may be more beneficial in insuring success of the streambank stabilization project. This can be accomplished by applying the concepts in the Channel Evolution Model (CEM) as developed by Schumm. This technique evaluates stream cross sections and assigns them to a stage. By doing so, the designer can better recommend appropriate solutions. The Channel Evolution Model is presented in Figure 3.

Channel Evolution Model

In Stage I, the channel is stable. The "h < hc" indicates that the height of the channel bank (h) is less than the critical height (hc) where slope failures begin to occur. The small channel carries a frequently occurring discharge, the runoff from a 1-5 year storm. Any storms with greater energy levels spill out on the adjacent flood plain. The water flows less deep and slower on the floodplain so little erosion occurs. In fact, deposition may occur on the floodplain. The stream and its floodplain are connected and the watershed and channel are in equilibrium.
Stage II in channel evolution is usually the initiation of incision or downcutting in the channel. This downcutting is in response to changes in the watershed or stream that result in higher runoff volumes or patterns. Changes in the watershed or stream include removal of vegetation, changes in land use, or straightening of the stream.

The deepened channel can now carry more runoff so more energy is being exerted on the soils in the channel bottom and banks than in Stage I. The height of the channel banks becomes greater due to downcutting. When the height of the banks exceeds the critical height, the channel banks begin to fail and the channel widening of Stage III begins.

Channel widening will continue until the stream bottom is wide enough to allow flows to spread out. Flows are not as deep and cannot move as much sediment as in Stage II. Eventually, the stream becomes wide enough that the sloughed materials that fall to the base of the failing banks are not flushed away with each flood. It should be noted that "bankfull" or "bankforming" discharge during Stage II and III will not necessarily be at the top of bank.

Stage IV in channel evolution, the stabilizing phase, is signaled by vegetation establishing itself at the base of the failing banks. Through time, a new, low capacity channel forms in the bottom of the deepened and widened channel.

Stage V begins when this new low-flow channel forms, and the stream has reached equilibrium once again. The active floodplain from Stage I is now high and dry as another terrace in Stage V.

Areas experiencing Stages II and III conditions are complex and most often require structural solutions. Bed degradation must be controlled prior to the installation of

streambank protection. Grade control structures should be designed to maintain the sediment transport capacity of the channel and provide for passing a wide range of flow velocities without creating backwater and causing sediment deposition. Vortex rock weirs, "W" rock weirs, and other rock/boulder structures that protect the channel without creating backwater should be considered instead of rock or log dams.

Determining the types and causes of erosion is also important. Information provided in Table 4 can be used as a guide in the planning and design process.

Hydraulic Requirements

All channels shall be analyzed for stability and capacity. Channel capacity at vegetative maturity shall not increase the frequency of out-of-bank flow.

Analysis, including stream stability should be evaluated by appropriate models such as velocity, regime theory, tractive stress, etc., as presented in Technical Release 25, or other engineering reference.

Monitoring of soil bioengineering projects to document "n" values immediately following installation has not been conducted. However, the information contained in Table 1 can be used as a guide to estimate resistance (Mannings "n").

Design discharge and/or hydrographs for capacity shall be determined by using appropriate analysis methods. Design storm events should be as defined in the standard for Stream Channel Stabilization-584.

Table 1 Manning's "n" for soil bioengineering practices

Soil Bioengineering System	Manning's "n" value*	
	Installation condition (stability)	Mature condition (capacity)
Conventional vegetation (use of the retardance method is required for designing grass lining)	0.025	0.055
Live staking Live fascines (wattling bundles) Branchpacking Brushmattress Live cribwall (similar to gabions in hydraulic effects)	0.025	0.1
Joint planting	0.025 - 0.04	0.1

* Mean value

As a minimum, bankfull flow (usually the 1.5-3.0 year storm) and the 10-year storm shall be evaluated for stability.

Maximum allowable velocities for bankfull and out of bank discharges as displayed in Figure 4 shall be based on allowable soil velocities in Table 2. Permissible velocities are based on the use of an erosion control fabric in conjunction with the soil bioengineering system.

Every reach shall be individually designed unless all reaches are designed for the worst cases for velocity and capacity, for example: most highly erodible soil, steepest slope, most confined cross-section, etc. As noted in the Streambank and Shoreline Protection Standard, stabilization designs must begin and end in a stable channel reach.

See Table 3 for a summary of soil bioengineering measures.

Table 2 Maximum Allowable Velocities for Soil Bioengineering Systems

USDA Soil Texture	Mean Velocity (fps) with matting *
Sand	2
Silt loam, sandy loam, loamy sand, loam and muck	5
Silty clay loam, sandy clay loam	5.5
Clay, clay loam, sandy clay, silty clay	6

* This table may be used as a guide if results from stability analysis are satisfactory. All soil bioengineering designs shall incorporate a biodegradable Coir (coconut fiber), jute blanket, or non-biodegradable blanket placed over seeded areas. They shall be integrated into the measure in accordance with USDA-NRCS EFH Chapters 16 and/or 18.

Table 3 Summary of Streambank / Shoreline Soil Bioengineering Measures

System Type	Zone of Application*	Types of erosion problems for which the system is suitable	Comments and Restrictions
Live stake	Bank Zone Upper Zone	general bank scour	Suitable for small, simple erosion problems when used in conjunction with other systems.
Live fascine (wattle)	Bank Zone Upper Zone	general bank scour, overbank runoff	Useful for moderate to severe erosion.
Branchpacking	Bank Zone Upper Zone	local bank scour, gullies eroded by overbank runoff	Restricted to repair of small sites (maximum depth 4 feet.)

System Type	**Zone of Application***	**Types of erosion problems for which the system is suitable**	**Comments and Restrictions**
Vegetated Geogrid	Toe Zone Bank Zone Upper Zone	toe erosion, local bank scour	Useful on steep slopes (up to 0.5H:1V) where space is limited.- generally restricted to heights not exceeding 6 feet overall. - Requires site specific soils data and design.
Live cribwall	Toe Zone Bank Zone Upper Zone	local bank scour, toe erosion (requires structural toe protection)	Useful on steep slopes (up to 0.5H: 1V) where space is limited/ generally restricted to heights not exceeding 6 ft. overall. -Requires specific engineering design.
Joint Planting	Bank Zone Upper Zone	general and local bank scour; toe erosion	Requires specific engineering design.
Conventional Turf vegetation	Bank Zone Upper Zone	general & local bank scour, toe erosion (requires structural toe protection such as gabions or rip rap)	Restricted to low energy channel banks or out of bank areas.
Tree revetment	Toe Zone Bank Zone	general and local scour; toe erosion	Provides temporary protection. -Encourages soil deposition at toe.
Rock Riprap (including gabions)	Toe Zone Bank Zone Upper Zone	local & general bank scour; toe erosion	For headcutting and general bed degradation.
Coir (coconut fiber) logs	Toe Zone Bank Zone	Toe erosion	Must be 2/3 submerged in water to be an effective rooting medium.
Brush Roll (inert fascine)	Toe Zone Bank Zone	Toe erosion	Must be 2/3 submerged in water to be an effective rooting medium.

Chart adapted from Robbin B. Sotir & Associates

* See page 6 for Zone of Application descriptions.

Shorelines of lakes, ponds, and embayments offer different site conditions which must be evaluated. To determine the potential of effectively stabilizing these sites with vegetation alone, refer to the process contained in the Soil Bioengineering Vegetative Treatment Potential for Ponds and Lakeshores (VTP) (Table 4). Potential use and water salinity will dictate selection of vegetative species.

VEGETATION

Plant species must be suitable for the intended use and adapted to the site's climate, soil, and water conditions. Species that root easily, such as willow, are required for such measures as live fascines, vegetated geogrid, and live staking or where unrooted stems are used with structural measures. Plant materials will be live, viable woody or herbaceous vegetation. The plant materials will be obtained from commercial sources or, in the case of woody cuttings, may be harvested from native stands during the dormant period (October - April depending on location). Plant materials shall be installed singly or in systems as described in USDA - Natural Resources Conservation Service, Engineering Field Manual, Chapter 16 (for stream practices) and Chapter 18 (for Upland practices).

Plant Adaptation Zones

Toe Zone (Base flow) - Water surface supported by groundwater discharge or where side slopes meet channel bottom (intermittent streams). Often too wet to grow vegetation. Select vegetation which develops an extensive root system and tolerates extended saturation. This includes Obligate and Facultative Wet herbaceous and woody plants.

Bank Zone (Above Base flow to top of bank; or 1-3 year storm elevation) - For natural streams it is the discharge that fills the channel without overflowing onto the flood plain. For modified or entrenched streams it is the streamflow volume and depth produced by the 1-3 year frequency flow event. It is the area where the discharge determines the streams geomorphic planform dimensions. Select vegetation which tolerates wetting and drying soils and ice scour where applicable. This includes Facultative and some Facultative Wet grasses, forbs and shrubs.

Upper Zone (Out of bank, Terrace) - Is that area landward from the bank and subjected to inundation or erosive action only occasionally. It is characterized by a large increase in flow width with a small increase in elevation. Select vegetation which tolerates droughty conditions and ice scour where applicable. This may include some Facultative and most Facultative Upland plants.

Plant Material Specifications

* <u>Rooted seedlings</u> - Plants shall be at least 12" long. The root system shall have approximately the mass equal to the top portion.

* <u>Unrooted cuttings</u> - Cuttings shall be 8" - 18" in length and 1/4" -1/2" in diameter.

* <u>Live Stakes</u> - cuttings shall be 2.0' to 3.0' in length and 1/2" to 2.0" in diameter.

* Posts - cuttings shall be 4' to 10' in length and 2" - 6" in diameter.

* Live brush - Live brush will consist of the whole above ground portion of willow, redosier dogwood, or other hardwood species which root easily from cuttings. Plants shall be 4 to 8 feet in height and free of disease. When there is a shortage of live, dormant brush, up to 30% of nonrooting species may be mixed randomly with the rooting species. Brush will be cut by shears or saw, not an ax.

* Herbaceous plants - Grasses, sedges, and rushes shall be provided in multiple-clumped pots having a minimum of two stems per pot. Stems shall have a minimum length of 6".

Plant Selection - See Table 6 - Shrubs Suitable for Soil Bioengineering Systems in NRCS - East Region for species adaptations.

a. Herbaceous plant materials suitable for use in coir fiber rolls. Recommend a mixture of the following:

Asclepias incarnata - Swamp milkweed
Acorns calamus/americanus - Sweet Flag
Calamagrostis spp. - Bluejoint reedgrass
Carex spp. - Sedges
Cinna arundinacea - Wood reedgrass
Distichlis spicata - Seashore saltgrass
Eupatorium purpureum - Joe Pye weed
Glyceria spp. - Mannagrasses
Iris versicolor - Blueflag iris
Juncus spp. - Rushes
Leersia oryzoides - Rice cutgrass
Lobelia cardinalis - Cardinal flower
Pontederia cordata - Pickerelweed
Sagittaria latifolia - Duckpotato
Scirpus spp. - Bulrushes
Sparganium spp. - Burreed
Spartina spp. - Cordgrasses
Typha spp. - cattails

b. Woody plants shall consist of bareroot plants or unrooted cuttings and stem (whips) of hardwood shrub species which root easily. Plant materials may come from nursery sources, plant materials centers or existing local stands.

Plant materials suitable for use as rooted or unrooted cuttings include:

Cephalanthus occidentalis - buttonbush
Baccharis halimifolia - groundselbush
Cornus amomum - silky dogwood
Cornus serecia - redosier dogwood
Cornus racemosa - gray dogwood
Salix purpurea - Streamco purpleosier willow
Salix cottetii - Bankers dwarf willow
Salix exigua - sandbar willow
Salix discolor - pussy willow
Salix nigra - black willow
Sambucus canadensis - elderberry

Viburnum dentatum - southern arrowwood
Viburnum lentago - nannyberry
Viburnum prunifolium - blackhaw

c. Plant materials suitable for use only as bareroot plants include:

Alnus rugosa - speckled alder
Alnus serrulata - smooth alder
Amorpha fruticosa - indigobush
Aronia arbutifolia - red chokecherry
Clethra alnifolia - sweet pepperbush
Ilex verticillata - winterberry holly
Lindera benzoin - spicebush
Physocarpus opulifolius - ninebark
Prunus pumila var. depressa - dwarf sand cherry
Rhododendron viscosum - swamp azalea
Rosa palustris - swamp rose
Spirea tomantosa - steeplebush

PLANS AND SPECIFICATIONS

Plans and specifications for streambank and shoreline protection should be prepared for specific field sites as based on these guidelines. Plans and specifications include construction plans, drawings, job sheets, construction specifications, narrative statements in conservation plans, or other similar documents. These documents should specify the requirements for installing the practice, such as the kind, amount, or quality of materials to be used, or the timing or sequence of installation activities.

OPERATION & MAINTENANCE

Vegetated streambanks are vulnerable to damage and repairs may be necessary. Maintenance of new installations shall consist of replacing, weeding, spraying, repairing of gully erosion or washouts and keeping project free of insects and diseases. If streambank had previously been used as an access point for recreation or other functions, periodic checks should be made to insure designated access points are functioning properly. Riparian areas should be checked after every high-water event. Repair or replace structural or vegetative areas with new materials. Fresh cuttings from other plants on the bank may be used.

Table 4 Types and Causes of Erosion

TYPES AND CAUSES OF EROSION	
Type of Erosion	**Causes**
Toe erosion and upper bank failure	Removal of unconsolidated or noncohesive lower soil materials, especially along outside stream bends. Widespread toe erosion and upper bank failure may be associated with bed lowering.
General bed degradation (Bed scour over extended reaches)	Changes in stream gradient due to factors such as lowering of stream base level due to lake or tailwater fluctuations, stream channelization or stream relocation. Increased stream discharge due to flow diversion or watershed changes such as urbanization.
Headcutting	In stream undergoing bed degradation, headcuts often develop at locations where more resistant materials out crop in the stream channel. Headcuts may develop at a stream mouth when base level is lowered suddenly due to dredging, erosion or draining of a lake.
Middle and upper general bank scour	Increased discharge resulting from watershed changes; increased flow velocities caused by reduction in channel roughness or increased gradients; removal or loss of bank vegetation.
Local streambank scour	Scour of local lenses or deposits of unconsolidated material; erosion by secondary currents caused by flow obstructions and obstructions and channel irregularities; loss of bank vegetation.
Local bed scour	Local bed scour may be caused by channel constrictions, flow obstructions such as debris dams or flow deflectors, or trapping of sediment in reservoirs or sediment traps. Some scour generally occurs below culverts.
Piping	Piping develops when fines are removed by water flowing laterally under the surface. Extensive piping develop requires 1) rapid infiltration, 2) steep hydraulic gradients, and 3) zones of concentrated flow. Piping may occur in stratified soils where vertical movement is restricted by sudden reduction in hydraulic conductivity between strata or where poorly compacted soil around buried pipes provides conduits for water movement.
Overbank runoff	Failure to provide adequate means of directing concentrated flows from overbank areas into the channel.

Prepared by: Robbin B. Sotir & Associates

Table 5 Soil Bioengineering Vegetative Treatment Potential (VTP) for Ponds and Lake Shores

Shoreline Variables	**Directions for Use:** Enter the applicable VTP rating (bold Number) in the last column. Add the total of the VTP ratings and compare with the Treatment Potential (TP) scale below.					VTP Factor
1. **Fetch:** Average distance in miles of open water measured perpendicular to the shore and 45 degrees either side of perpendicular to shore	**Less than 0.5 miles** **8**	**0.5 to 1.4 miles** **7**	**1.5 to 3.4 miles** **4**	**3.5 to 4.9 miles** **2**	**over 5.0 miles** **0**	
2. **General shape of shoreline** for distance of 200 yards on each side of planting site	Coves 8	Irregular shoreline 3		Headland or straight shoreline 0		
3. **Shoreline orientation:** General geographic direction the shoreline faces.	Any less than 1/2 mile fetch 5	West to North 3	South to West 2	South to East 1	North to East 0	
4. **Boat traffic:** Proximity of the site to recreational and commercial boat traffic.	None 5	1-10 per week within 1/2 mile of shore 3	More than 10 per week within 1/2 mile of shore 2	1-10 per week within 100 yards of shore 1	More than 10 per week within 100 yards of shore 0	

VTP = Summation of VTP factors for shorelines variables 1, 2, 3, and 4

Vegetative Treatment Potential (VTP) Scale

if VTP is,

Between		And	Potential of site to be successfully stabilized with soil bioengineering
23	to	26	Excellent
20	to	22	Very Good
16	to	19	Good
13	to	15	Fair
<13			Poor

Note: Fair or poor sites shall use structural measures

Table 6 - Shrubs suitable for Soil Bioengineering Systems in NRCS - East Region

Species	Habitat	Bank Zone	Root Form	Shade Tolerance	Flood Tolerance	pH Range	Comments
Alnus serulata **Smooth Alder**	nontital	toe	rooted	medium	regular	5.5-7.5	Nitrogen fixer weak wooded
Amorpha fruiticosa **False indigo**	tidal fresh moist woods	lower- mid	rooted	low	seasonal	6.0-8.5	Reg. full sun Drought tolerant
Aronia arbutifolia **Red chokeberry**	nontidal	lower-mid	rooted	medium	irregular seasonal	5.1-6.5	Drought tolerant
Aronia melanocarpa **Black Chokeberry**	nontital	mid-upper	rooted	low	irregular	5.1-6.5	Drought tolerant
Baccharis halimifolia **Groundsel bush**	tidal tidal fresh	mid-upper	rooted unrooted	high	seasonal	7.0-8.5	M/F separate plants
Cephalanthus occidentalis **Buttonbush**	nontidal tidal fresh	toe	rooted unrooted	high	permanent	6.1-8.5	Tolerates brief drought
Clethra alnifolia **Sweet pepperbush**	tidal nontidal	mid-upper	rooted	high	seasonal	4.5-6.5	
Cornus amomum **Silky dogwood**	streambanks pond edges	lower-mid	rooted unrooted	medium	seasonal	5.5-8.5	Drought tolerant
Cornus racemosa **Gray dogwood**	streambanks pond edges	lower-mid	rooted unrooted	high	seasonal	5.5-8.5	Drought tolerant
Cornus serecia **Redosier** dogwood	streambanks pond edges	toe-mid	rooted unrooted	medium	seasonal	5.5-8.5	Drought tolerant
Ilex decidua **Possumhaw**	forested wetlands, pond edges	lower-mid	rooted unrooted	high	irregular	4.0-6.0	M/F separate plants
Ilex glabra **Inkberry**	forested wetlands, sandy woods	mid-upper	rooted	high	irregular inundation	4.5-6.0	M/F separate plants. Resists salt spray
Ilex verticillata **Winterberry holly**	tidal ,fresh forested wetland	lower-mid	rooted	high	seasonal	4.5-8.0	Drought tolerant
Itea virginica **Virginia Sweetspire**	forested wetland, streambanks	toe	rooted	high	regular	5.0-7.0	Tolerates some salt
Iva frutescens **Hightide bush**	tidal brackish	lower	rooted	low	regular	6.0-7.5	Tolerates 15 ppt salt
Leucothe racemosa **Leucothe**	forested wetlands, moist woods	lower-mid	rooted	high	regular	5.0-6.0	Tolerates some dry-down
Lindera benzoin **Spicebush**	seasonal wetlands, floodplain	lower-mid	rooted	high	seasonal	4.5-6.5	Tolerates some drought
Lyonia ligustrina **Maleberry**	open woods	lower-mid	rooted	low	seasonal	4.0-6.0	Acid tolerant
Magnolia virginiana **Sweetbay magnolia**	streambanks, forested wetland	lower-mid	rooted	high	irregular/ seasonal	4.0-6.5	Tolerates infreg. flooding by salt
Myrica cerifera **Wax myrtle**	tidal, fresh brackish swales	mid-upper	rooted	high	regular	4.0-6.0	tolerates 10 ppt salt; N-fixer
myrica pennsylvanica **Bayberry**	tidal fresh brackish nontidal	mid-upper	rooted	high	irregular seasonal	5.0-6.5	Tolerates drought, N-fixer
Physocarpus opulifolius **Ninebark**	streamsides woodedges	low-mid	rooted	medium	seasonal		
Prunus pumila var. depressa **Dwarf sand cherry**	streamsides sandbars	mid-upper	rooted	low	irregular	6.5-8.5	Native to Delaware R. Groundcover
Rhododendron viscosum **Swamp azalea**	forested wetlands	toe-low	rooted	medium	seasonal-regular	4.0-6.0	susceptible to disease

Table 6 - Shrubs Suitable for Soil Bioengineering Systems in NRCS - East Region (cont.)

Species	Habitat	Bank Zone	Root Form	Shade Tolerance	Flood Tolerance	pH Range	Comments
Rosa palustris **Swamp rose**	tidal fresh forested wetland streambank	toe-low	rooted	low	seasonal - regular		
Rhus typhina/glabra **Staghorn/Smooth sumac**	disturbed banks dry sites	upper	rooted	low	irregular	6.1-7.0	tolerates drought
Salix X cotteii **"Bankers" Dwarf willow**	streambank	toe-mid	unrooted rooted	medium	regular-permanent		introduced male hybrid-noninvasive
Salix discolor **Pussy willow**	streambank forested wetland	toe-mid	unrooted rooted	medium	regular-permanent	6.6-7.5	
Salix exigua **Sandbar willow**	streambank sandbars	toe	unrooted rooted	low	regular permenant		
Salix purpurea "streamco" **"Streamco" purpleosier willow**	streambank	toe-upper	unrooted rooted	medium	regular permanent	6.0-7.0	introduced noninvasive shrub
Sambucus canadensis **Elderberry**	tidal fresh nontidal wet meadow	low-mid	rooted unrooted	high	irregular seasonal	6.0-8.0	some salt tolerance tolerates drought
Spirea alba tomentosa **Meadowsweet**	forested wetland	mid-upper	rooted	low	irregular	5.1-6.0	
Viburnum dentatum **Southern Arrowwood**	tidal fresh nontidal forested wetland	mid-upper	rooted unrooted	medium	seasonal	5.1-7.0	tolerates drought
Viburnum lentago **Nannyberry**	forested wetland	mid-upper	rooted unrooted	medium	seasonal		
Viburnum prunifolium **Blackhaw viburnum**	forested wetland	upper	rooted unrooted	medium	irregular	6.5-7.0	
Viburnum trilobum **Am. cranberrybush**	forested wetlands	lower-mid	rooted unrooted	low	irregular-seasonal	6.0-7.5	tolerates drought

Footnotes:

1. Habitat:
   Native habitat of the plant.

2. Bank Zone:
   toe - elevation of baseflow
   lower to mid - from base to two year flood elevation
   upper - above two year elevation to flood plain

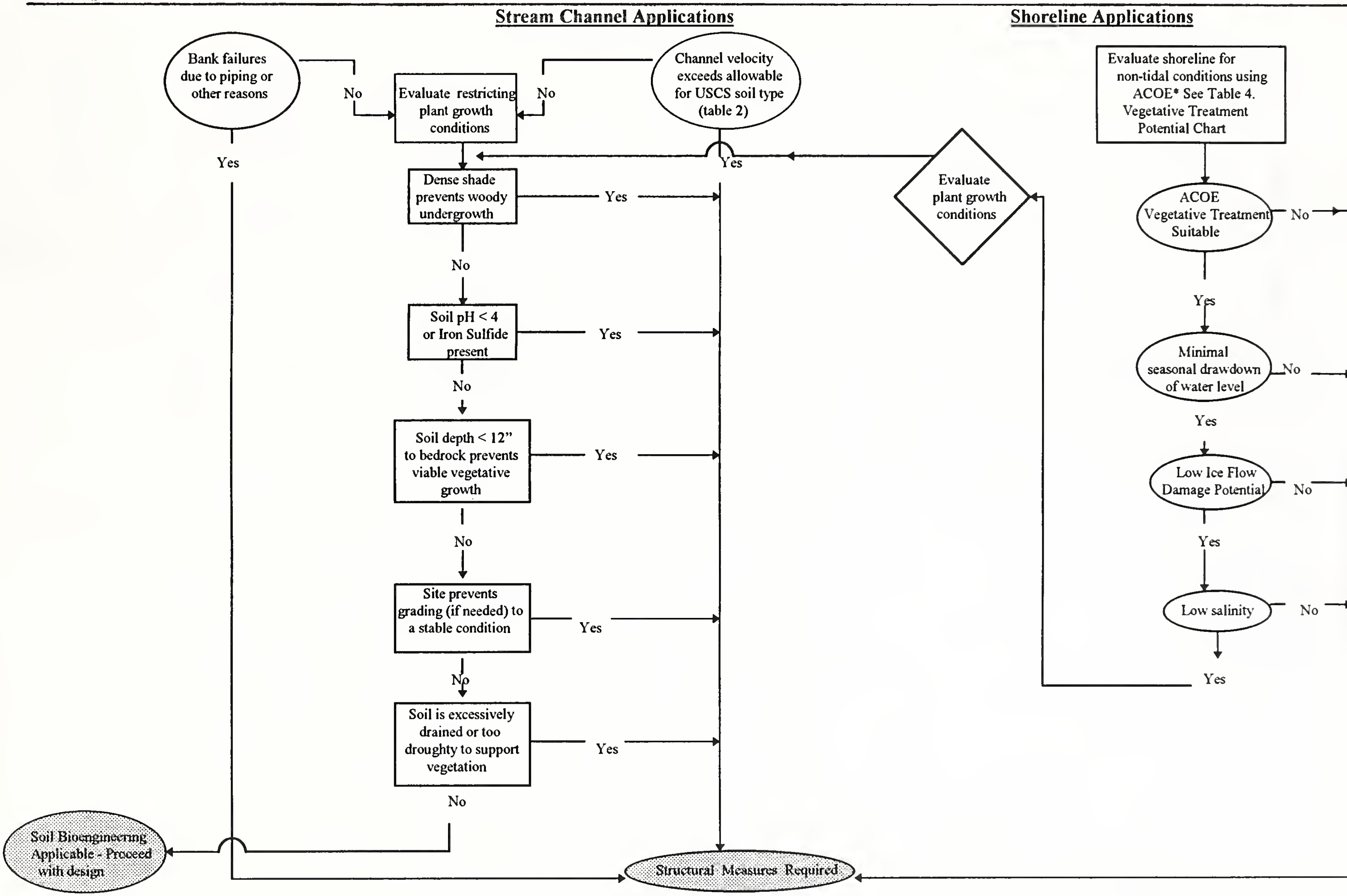
3. Root form:
   rooted - use bare root plants
   unrooted - use dormant cuttings/brush

4. Shade Tolerance:
   low - requires full sun
   medium - tolerates partial shade and full sun
   high - tolerates shade and full sun.

5. Flood tolerance:
   permanent - tolerates inundation or saturation 76-100% of the growing season.
   regular - tolerates inundation or saturation 26-75% of the growing season.
   seasonal - tolerates inundation or saturation 13-25% of the growing season.
   irregular - tolerates inundation or saturation 5-12% of the growing season.

6. pH range:
   preferred range for successful plant establishment.

Figure Soil Bioengineering Application Chart



* U.S. Army Corps of Engineers

Figure 2 Determination of Hazard Class for Steambank and Shoreline Protection

HAZARD CLASS

A hazard classification can be used to determine the level of design needed for the streambank protection measure. The hazard classes are:

(a) Low Hazard - sites involving undeveloped land such as woodland, agricultural uses, and open space.

(b) Medium Hazard - sites involving uninhabited structures, transportation networks of statewide importance, and other improved property where loses would be considerably more than the voiding of the land itself.

(c) High Hazard - sites involving dwellings, frequently inhabited structures, interstate highways, and other structures which if imperiled would threaten the life and safety of people.

DESIGN CRITERIA

The following table provides criteria for design:

Hazard Class	Design Storm	Stability Check	Bedding Requirement
a	2-10 yr.	bankfull or 10 year, whichever is lower	None if bank is gravel; otherwise use gravel from a nearby source or, if none available, use 15% to 25% gravel in rock
b	25 - 50 yr.	design storm	Same as "a" except use of gravel in riprap in lieu of bedding not permitted
c	100 yr.	100 yr.	Same as "b"

Figure 3 Channel Evolution Model

Channel systems may exhibit one or more types of sections from these typical cross sections.

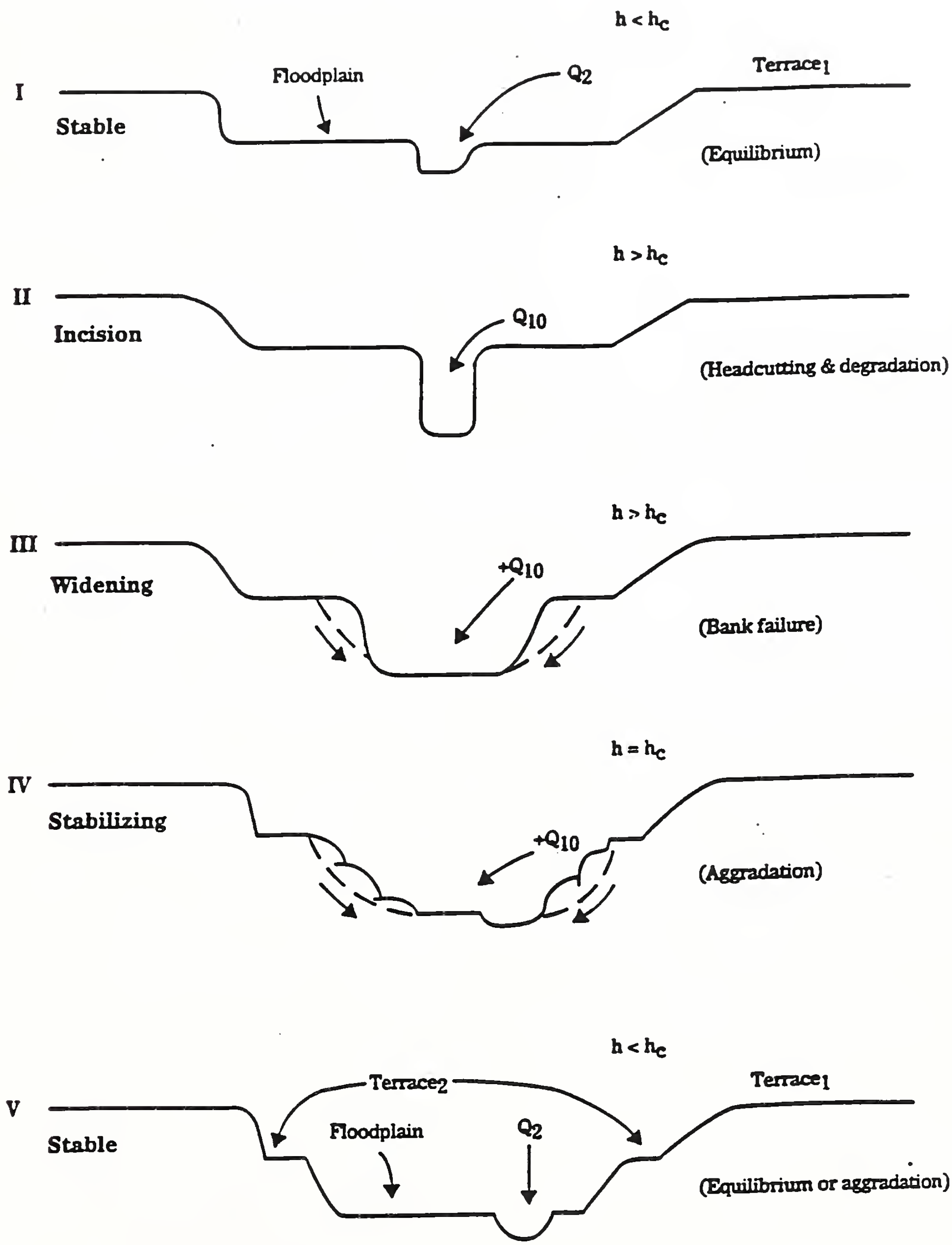
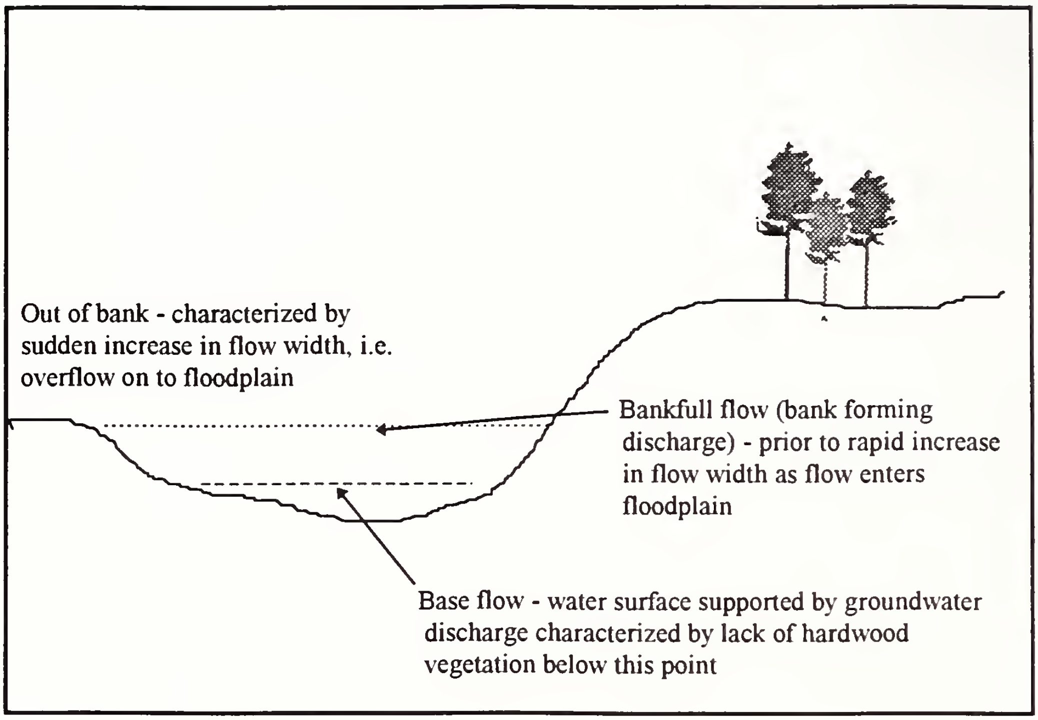


Figure 4 **Channel Flow descriptions in streambank stabilization practices**



EAST REGION
NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

Streambank and Shoreline Protection (580)
(Feet)

DEFINITION

Using vegetation and/or structures to stabilize and protect banks of streams, lakes, estuaries, or constructed channels against scour and erosion. Live and herbaceous plant material may be used alone or in combination with structural components such as rock, wood, concrete, or geosynthetics.

PURPOSE

To stabilize or protect banks of streams, lakes, estuaries, or constructed channels for one or more of the following purposes:

1. To prevent erosion and protect utilities, roads, buildings, or other facilities adjacent to the banks,
2. To maintain the capacity of the channel,
3. To control channel meander that would adversely affect downstream facilities, while accommodating the natural fluvial processes of the watershed,
4. To reduce sediment loads causing downstream damages and pollution, or
5. To improve the stream and shoreline corridors for recreation or as a habitat for fish and wildlife.

CONDITION WHERE PRACTICE APPLIES

This practice applies to natural or constructed channels where the streambanks are susceptible to erosion from the action of water, ice or debris, or have been previously damaged by livestock, pedestrians, or vehicular traffic. Streambeds must be stable and not subject to excessive degradation and scour or shall be protected from excessive head cutting or down cutting. It also applies to controlling erosion on shorelines where the problem can be solved with relatively simple structural measures and/or vegetation, and where failure of structural measures will not create a hazard to life or result in serious damage to property.

CRITERIA

Designs for ***streambanks*** shall be according to the following principles:

1. Streambank protection shall be started at a stabilized or controlled point and ended at a stabilized or controlled point on the stream.
2. Design discharge and/or hydrographs for capacity shall be determined by using appropriate analysis methods, such as:
   a. NRCS Technical Releases No. 55, No. 20, or U.S. Army Corps of Engineers HEC-1,
   b. EFH, Chapter 2 or other approved methodology
3. Stability design shall be determined using appropriate analysis methods, such as NRCS Technical Release No. 20.
4. A water surface profile analysis (such as WSP2, HEC-2) or other appropriate method, shall be used to determine channel flow characteristics.
5. Unless the protection can be safely constructed to a depth well below the anticipated lowest depth of bottom scour, excessive bed degradation must be controlled prior to the installation of streambank protection. Refer to standard for Stream Channel Stabilization-584.
6. Changes in channel alignment are not recommended unless the changes are based on a thorough evaluation of the proposed channel

change together with an assessment of both upstream and downstream geomorphology. The current discharge - sediment regime should be based on an assessment of the entire watershed above the proposed channel alignment.
7. Steep, unstable slopes and deep undercuts in banks will require grading to a stable slope or will require structural measures such as cribwalls, rock riprap, gabions, rootwads, bulkheads, or other appropriate techniques. For planting purposes, the steepest acceptable slope is 1.5 horizontal to 1.0 vertical. Slope stability analysis and design shall be subject to acceptable engineering practice and municipal, county, and state regulations. Newly graded banks may require protection from overbank flow. Refer to the Standard for Diversions-362.
8. Vegetative protection shall be considered above the 2 year storm water surface elevation, whether or not it requires incorporation with other measures.
9. Where deterioration of the streambank is caused or accelerated by vehicular, pedestrian, or livestock traffic, artificial obstructions for exclusion (such as fences) or designated travelways for access will be provided.
10. Structural and soil bioengineering measures shall be utilized individually or in combination with other systems to provide an appropriate level of protection based on design flows and hazard classification of the area being protected. Refer to East Region Supplement #1 to Chapter 16, EFH, for hazard classification system. All measures shall be designed to avoid undesirable impacts upstream and downstream.
11. A 15 foot minimum buffer width from the top of the bank shall be established in grass and/or woody plants.
12. Appropriate soil bioengineering measures may be found in EFH Chapter 16 and East Region Supplements.

Designs for ***shoreline protection*** shall be according to the following principles:

1. Recommended treatment shall be based on water salinity, and on soil type and slope characteristics both above and below the waterline. Slope characteristics below the waterline shall be representative of the slope for a minimum 50 foot distance from the shore.
2. End sections shall be adequately integrated with existing measures or terminate in stable areas.
3. Steep, unstable slopes and deep undercuts in banks will require grading to a stable slope or will require structural measures such as cribwalls, rock riprap, gabions, or other appropriate techniques. For planting purposes, the steepest acceptable slope is 1.5 horizontal to 1.0 vertical. Slope stability analysis and design shall be subject to municipal, county, and state regulations. Newly graded banks may require protection from overbank flow in accordance with the Standard for Diversions-362.
4. Vegetative protection shall be encouraged on eroding banks, especially on areas that are not susceptible to frequent or daily inundation.
5. Where deterioration of the streambank is caused or accelerated by vehicular, pedestrian, or livestock traffic, artificial obstructions for exclusion (such as fences) or designated travelways for access will be provided.
6. A 15-foot minimum width buffer area from the top of bank shall be established in grass and/or woody plants.
7. Appropriate soil bioengineering measures may be found in EFH Chapter 16 and East Regional Supplements.

Vegetation

Plant species must be suitable for the intended use and adapted to the site's climate, soil, and water conditions. Species that root easily, such as willow, are required for such measures as live fascines, brushlayer, and live staking or where unrooted stems are used with structural measures. Plant materials will be live, viable woody or herbaceous vegetation. The plant materials will be obtained from commercial sources or, in the case of woody cuttings, may be harvested from native stands during the dormant period (October - April depending on location). Plant materials shall be installed singly or in systems as described in USDA - Natural Resources Conservation Service, Engineering Field Handbook, Chapter 16.

CONSIDERATIONS

1. Attention shall be given to maintaining or improving habitat for fish and wildlife.
2. Consideration shall be given to using construction materials, grading practices, vegetation, and other site development elements that minimize negative visual impacts and maintain or complement desirable landscape

features such as pedestrian pathways, greenways, forested buffers, etc.
3. Consideration shall be given to the water quality filtering effects of vegetation on movement of sediment, and sediment-attached and dissolved substances.
4. Consideration shall be given to the water quality effects on erosion and movement of sediment, and soluble and sediment-attached substances carried by runoff and streamflow.
5. Consideration shall be given to the water quality effects of changes in water temperature.
6. Consideration shall be given to the water quantity effects on the water budget, especially on volumes and rates of runoff, infiltration, deep percolation, and water recharge.
7. Consideration shall be given to the water quantity effects on downstream flows and aquifers that affect other uses and users.
8. Consideration shall be given to the water quantity effects on the water table of adjoining fields and the effects on the interflow discharge into streams.
9. Structural measures shall be designed for anticipated ice action.
10. Planning, design, and installation of streambank or shoreline practices will be performed in accordance with acceptable engineering practice and local, state, and federal government regulations.
11. Costs of measures vary widely and must be evaluated for monetary cost versus risk.
12. Plant materials of adequate quantity and quality are often a scarce resource. Their availability is critical to soil bioengineering solutions.

PLANS AND SPECIFICATIONS

Plans and specifications for streambank and shoreline protection shall be prepared for specific field sites and based on this standard. Plans and specifications include construction plans, drawings, job sheets, construction specifications, narrative statements in conservation plans, or other similar documents. These documents are to specify the requirements for installing the practice, such as the kind, amount, or quality of materials to be used, or the timing or sequence of installation activities.

OPERATION AND MAINTENANCE

The streambank or shoreline protection was designed and installed to stabilize an eroding area. The estimated life span of this installation is at least 10 years. The life of this installation can be assured and usually increased by developing and carrying out a good operation and maintenance program. This practice will require periodic maintenance and may also require operational items to maintain satisfactory performance.

REFERENCES

* Chapter 16, EFH; Chapter 18, EFH;
* TR20, TR25, TR55, EFH 2, HEC-1
* USDA-NRCS National Planning Manual
* East Region Supplement #1, Chapter 16, EFH
* Riparian Forest Buffer (391)
* Filter Strip (393)

SUMMARY OF SCS BIOENGINEERING TRIALS

A. Nursery Grown vs 'Wild' Collected Material

* Nursery grown plants have outperformed locally collected plant material on most projects where comparisons were designed.

* The use of improved plants (cultivars) tend to reduce the risk of plant failure because of the improved vigor. However, cultivars are not a panacea for all sites. Indigenous or native material may be more appropriate on ecologically sensitive project sites. Selection of plant material should be based on specific site conditions.

* When large quantities of plant material are required such as for wattling, brushlayering or brushmattressing, a mixture of locally collected live and dead brush may be mixed with nursery grown material.

B. Success of Unrooted vs Rooted cuttings

* Success of small unrooted cuttings, live stakes, and willow poles have been extremely variable depending upon soil moisture, depth of planting, and weather conditions.

* Unrooted material is most successful on finer-textured soils and on lower bankslope elevations. The higher in elevation on the slope, the longer the cuttings should be to extract deep soil moisture. Use of erosion control blankets generally improve survival rates due to moisture conservation.

* Rooted material generally outperforms unrooted at higher elevations on the slope and on coarser-textured soils. Root gel improves survival rate.

* On upslope areas, fall planting has been more successful than spring planting.

C. Wattle Construction and Placement

* This technique has proven to be fairly reliable. It has been most successful when used within four foot of the water line.

* Wattle core may be composed of lumber or dead limbs to increase bulk and conserve the use of live material, thereby reducing costs. Two to three inch diameter wattles are a suitable size for effective plant establishment.

* On sloping ground where wattle size may help support slope stability, larger size wattles (6"-12" diameter) wattles are more effective.

* Where wattles are used with erosion control blankets, the wattles perform better if placed in trench on top of the blanket. Suppression of sprouting occurs when the blanket is placed over the wattle.

D. Brushmattress Technique

* Along with wattling, this was one of the earliest bioengineering techniques used. It is suitable for use where grading is a problem and a large quantity of brush is available.

* Incorporate brush of woody, wetland plants such as alder if done in the Fall. Then it contains ripe seed which may germinate and add living material to the site. Evergreen brush is good for the protective cover it provides.

E. Herbaceous Companion Plantings

* Competition concern: Avoid tall fescue, reed canarygrass and competitive legumes such as crownvetch and flatpea. If a cool-season grass is used, select a short-lived perennial such as perennial ryegrass or redtop seeded lightly.

* If the site is particularly droughty and coarse-textured, native warm-season grasses should be selected. Beachgrass has also been successfully used between rows of wattles on dry, sandy sites.

* Wildflower mixes containing a small percentage of fine fescue, such as hard or sheep fescue provide aesthetics to the site.

F. Erosion Control Blankets

* Use improves moisture conservation in the soil for increased seedling survival and rooting success. This is especially true for dry, coarse-textured sites.

* Help prevent scour under high flows. Choose 100% coconut or 70% coconut-30% straw blankets for in-stream locations. Coconut blankets are recommended for velocities up to 8 ft/sec. Straw blankets or mulch may be used further upslope.

* Carefully follow manufacturers guidelines for installation regarding stapling and anchoring at the edges.

* Rooted and unrooted cuttings may be planted through the blankets.

PLANT MATERIALS COST ESTIMATES FOR BIOENGINEERING PRACTICES

Woody material costs (Shrub willows and dogwoods)

* Unrooted cuttings (10"-18"); .25 -.50 ea. (18" spacing)

* Rooted cuttings (8"-12"); $1.00 ea. (18" spacing)

* Unrooted whips (4'-8'); .15 - .25 ea.

* Live stakes (0.5"-1.5" dia., 2'-3'length, unrooted material, 2'-3' spacing); $1.00 ea.

* Wattles (4" dia., 6'foot length); $3.00-$5.00/lin. ft. installed.

Herbaceous material costs (Sedges, Rushes, Grasses)

* Peat pots (1.75"-3"); 0.65 - $1.50 ea.

* Bare root; 0.25 - $1.00 ea. (varies greatly by species)

* Rootstock; 0.50 - $1.50 ea. (varies greatly by species)

* Plant plugs; 0.75 - $1.25

These are average and approximate costs of materials only from four local and prominent plant suppliers.

Coir (coconut) fiber rolls (12" diameter, 20' length)

* Fiber roll; $9.00 - $11.00/linear ft.

* Fiber roll + installation; $11.00 - $15.00/linear ft.

* Biolog (Fiber roll + plants, installation); $15.00 - $17.00/linear ft.

Coconut/Straw Erosion Control Blankets

* 100% straw - $.10/sq. ft.

* coconut/straw combination - $.15/sq. ft.

* 100% coconut - $.18/sq. ft.

Other Materials; stakes, twine, seed - $3.00/ft.

Compiled by Chris Miller; 8/12/93, Revised 11/18/94

SUPPLIERS OF BIOENGINEERING PRODUCTS

Bestmann Green Systems, Inc.
53 Mason St.
Salem, MA 01970
(508) 741-1166
* Supply coconut fiber products and plants

BonTerra America, Inc.
P.O. Box 9485
Moscow, ID 83843
(800) 882-9489

Local suppliers: Pinelands Nursery
323 Island Road
Columbus, NJ 08022
(609) 291-9486
* Supply coconut fiber products and plants

Ragen Associates
P.O. Box 169
Edison, NJ 08818
(908) 561-1010
* Supply geotechnical products

Creative Habitat Corp.
253 Old Tarrytown Rd.
White Plains, NY 10603
(914) 948-4389
* Supply coconut fiber products and plants

Eastern Products, Inc.
1162 Sycamore Lane
Mahwah, NJ 07430
(201) 934-5050
* Supply coconut fiber products

Ernst Crownvetch Farms
RD #5, Box 806
Meadville, PA 16335
(800) 873-3321
* Supply plants for bioengineering systems

New England GeoTextiles Co., Inc.
9 Palfrey St.
Worcester, MA 01604
(508) 756-3734
* Supply coconut fiber products

PLANT DEALERS

PLANTS FOR BIOTECHNICAL STABILIZATION

Common_name	Scientific_name	Cultivar	Dealer_code
Alder, smooth	Alnus serrulata	common	MD02p,MD12p,NJ09p,NY13s,PA09p -
Dogwood, silky	Cornus amomum	common	CT01s,MA01p,MA02p,MA05s,MD02p, MD10p,MD12p,MD13p,NJ03p,NJ08p, NJ09p,NJ10p,NY13s,NY15p,NY18p, PA09p,PA10p,PA12p,PA16p,PA19p, PA22p,VA07p -
Dogwood, silky	Cornus amomum	Indigo	MD11p,NJ09p -
Dogwood, greystem	Cornus foemina racemosa	common	MD02p,MD13p,NJ09p,NY09p,NY13s, NY15p,PA09p,PA10p,PA19p,PA22p -
Dogwood, redosier	Cornus sericea (stolonifera)	common	MA01p,MA02p,MA05s,MD02p,MD10p, MD12p,MD13p,NJ11p,NJ12p,NY09p, NY13s,NY15p,NY18p,NY21p,PA12p, PA17p,PA19p,VA07p -
Dogwood, redosier	Cornus sericea (stolonifera)	Ruby	MD02p,MD11p,MD17p,NJ08p,NJ09p, PA05p,PA09p,PA10p,PA16p,PA20p, PA21p,PA22p -
Willow, dwarf	Salix x Cottetii	Bankers	MD02p,MD11p,NJ02p,NJ09p,NY20p, PA05p,PA10p,PA16p,PA18p,VA08p -
Willow, purpleosier	Salix purpurea	common	MA01p,MD13p,NY15p -
Willow, purpleosier	Salix purpurea	Streamco	MA10p,MD02p,MD11p,NJ09p,NY09p, NY17p,NY19p,NY20p,PA02p,PA05p, PA09p,PA10p,PA16p,PA22p -

* Note: p=plants, s=seed

PLANT DEALERS

Code	Dealer	Street	City	State	Zip	Phone
CT01	R. Herbst Wholesale Seed, Inc.	P.O. Box 108	New Fairfield	CT	06012	(203)-746-1842
MA10	Weston Nurseries	Rt. 135, P.O. Box 186	Hopkinton,	MA	01748	(617)-435-3414
MA01	Sylvan Nursery, Inc.	1028 Horseneck Road	South Westport	MA	02790	(508)-636-5615
MA02	Wanczyk Evergreen Nursery, Inc.	166 Russell Street	Hadley,	MA	01035	(413)-584-3709
MA05	F.W. Schumacher Co., Inc.	36 Spring Hill Road	Sandwich,	MA	02563	(508)-888-0659
MD02	Environmental Concern, Inc.	210 West Chew Ave., Box P	St. Michaels,	MD	21663	(410)-745-9620
MD10	Mike Banks Nursery	Rt.1, Box 489	Eden,	MD	21822	(410)-749-8994
MD11	Benedict Nurseries	Box 347A, Pemberton Dr.	Salisbury,	MD	21801	(410)-742-2266
MD12	Sylva Native Nursery	P.O. Box 299	Freeland	MD	21053-0299	(410)-560-2288
MD13	Rodney Witman Associates, Inc.	934 Ellendale Dr.	Towson,	MD	21204	(410)-823-4732
MD17	Gemma Garden Center & Nursery	11207 Race Track Road	Berlin,	MD	21811	(410)-641-5122
NJ02	Hess' Nurseries, Inc.	P.O. Box 326, Route 553	Cedarville,	NJ	08311	(609)-447-4213
NJ03	Princeton Nurseries	P.O. Box 191	Princeton,	NJ	08542	(609)-924-1776
NJ08	Croshaw Nursery	Box 255	Columbus,	NJ	08022	(609)-298-0477
NJ09	Pinelands Nursery	323 Island Road	Columbus,	NJ	08022	(609)-291-9486
NJ10	Arrowwood Nursery, Inc.	P.O. Box 418C, Malaga Rd.	Williamstown,	NJ	08094	(609)-753-1160
NJ11	Sepers Nursery	1003 Columbia Ave.	Newfield,	NJ	08344	(609)-691-0597
NJ12	Ferrucci Nurseries	Piney Hollow Rd. & Victoria Ave.	Newfield,	NJ	08344	(609)-697-1950
NY13	Sheffield's Tree & Shrub Seed	273 Auburn Rd., Rt. 34	Locke,	NY	13092	(315)-497-1058
NY09	Baier Lustgarten Nurseries	Route 25, Middle Island	Long Island,	NY	11953	(516)-924-3444
NY15	Southern Tier Consulting, Inc.	P.O. Box 550	Portville,	NY	14770	(716)-933-6169
NY17	Alleghany County SWCD	County Route 48, RD #2	Belmont,	NY	14813	(716)-268-7831
NY18	Bissett Nursery Corp.	P.O. Box 386	Holtsville,	NY	11742-0386	(516)-289-3500
NY19	Saratoga Tree Nursery	Route #5	Saratoga Springs,	NY	12866	(518)-885-5308
NY20	Treehaven Evergreen Nursery	981 Jamison Road	Elma,	NY	14059	(716)-652-4206
NY21	Peat & Son Nursery	32 Old Country Road	Westhampton,	NY	11977	(516)-288-3458
PA02	Appalachian Nurseries	Box 87	Waynesboro,	PA	17268-0087	(717)-762-4733
PA05	Hanchar's Superior Trees	RD #1, Box 118	Mahaffey,	PA	15757	(814)-277-6674
PA09	Ecoscience, Inc.	RR #4, Box 4294	Moscow,	PA	18444	(717)-842-7631
PA10	Musser Forests, Inc.	P.O. Box 340	Indiana,	PA	15701	(412)-465-5685
PA12	Pine Grove Nursery	RD #3, Box 146	Clearfield,	PA	16830	(814)-765-2363
PA16	Ernst Crownvetch Farms	RD #5, Box 806	Meadville,	PA	16335	(814)-425-7276
PA17	Carino Nurseries	P.O. Box 538	Indiana,	PA	15701	(412)-463-3350
PA18	Plunketts' Creek Nursery	Box 353, Proctor Star Route	Williamsport,	PA	17701	(717)-478-7035
PA19	Amenity Plant Products	RD #5, Box 265	Mt. Pleasant,	PA	15666	(412)-423-8170
PA20	Beebe Crownvetch Farm	RD #4, Box 226	Towanda,	PA	18848	(717)-265-6536
PA21	Penn Nursery	RD #1	Spring Mills,	PA	16875	
PA22	Howard Nursery	RD #2, Box 139	Howard,	PA	16841	(814)-355-4434
RI01	Bald Hill Nurseries, Inc.	90 Ten Rod Road	Exeter,	RI	02822	(401)-294-9100
VA07	Va. Department of Forestry	P.O. Box 160	Crimora,	VA	24431	(703)-363-5732
VA0[illegible]	Waynesboro Nursery	P.O. Box 987	Waynesboro,	VA	22980	(703)-942-9141

PLANT MATERIALS FOR SOIL BIOENGINEERING IN THE NORTHEAST

	Ht.	Spread	Status	Cultivar	Available Commercially
Willows					
purpleosier (*Salix purpurea*)	15	No	Naturalized	Streamco	yes
dwarf (*Salix x cottetii*)	8	Layering	Introduced	Bankers	yes
sandbar (*Salix exigua*)	20	Root-sucker	Native	(pending)	no
pussy (*Salix discolor*)	15	No	Native	(pending)	yes
Dogwoods					
redosier (*Cornus stolonifera*)	10	Layering	Native	Ruby	yes
silky (*Cornus amomum*)	10	Layering	Native	Indigo	yes
Miscellaneous					
dwarf sand cherry (*Prunus pumila v. depressa*)	1	Layering	Native	(pending)	no
smooth alder (*Alnus serrulata*)	20	Root-sucker	Native	(pending)	yes?
Grasses					
American beachgrass (*Ammophila breviligulata*)	2	rhizomatous	Native	Cape	yes
switchgrass (*Panicum virgatum*)	2	seed	Native	Shelter	yes
coastal panicgrass (*Panicum amarum v. amarulum*)	6	seed	Native	Atlantic	yes
big bluestem (*Andropogon gerardi*)	7	seed	Native	Niagara	yes
prairie cordgrass (*Spartina pectinata*)	7	rhizomatous	Native	(pending)	no

USDA - SOIL CONSERVATION SERVICE

PLANTING GUIDE

Purpleosier Willow
(Salix purpurea L.)

Description: Purpleosier willow is a medium to tall introduced shrub growing 10 to 20 feet high, with smooth, slender, tough, resilient branches, purplish at first but later changing to gray or olive-gray. The leaves arise in pairs but not quite opposite, are smooth tongue-shaped, finely-toothed near the tip only, two to four inches long, bluish-green above and pale below. The catkins are small, arise in almost opposite pairs, and mature in spring before the leaves come out.

'Streamco' purpleosier willow is a thicket forming shrub, sending up many branches from the roots. It spreads by stolons and layering of branches. Growth is rapid, reaching about two to five feet in two years; often to full height in five years. This species is also called basket willow.

Adaptation: Streamco is climatically adapted to all the northeastern states. Well-drained to imperfectly-drained soils are most suitable for this species. It can be planted on soils of any texture excepting those of low fertility.

Wattle Construction: Wattles are prepared by cutting young or mature branches from healthy willow plants. Branches should be separated into groups of somewhat equal length. Bundles, called wattles are constructed by placing the branches alternately butt to tip. This process will form a cigar shaped wattle. Completed wattles should be 4 to 6 inches in diameter and vary from 5 to 8 feet in length. They should be loosely secured with twine or other suitable binding material every 6 inches of length. Normally, wattles will arrive at the site already prepared. They can be prepared locally, whenever, suitable plant material is available at the site.

Establishment:
On cut and fill slopes, shaping of the grade may be necessary. If the slope is relatively unstable, reinforcing engineering structures may be required at the base. Water should be diverted to prevent any overland flow onto the slope. Cut or fill slopes are more likely to succeed than streambanks.

Streambanks that are eroding, undercut or have steep slopes may need to be regraded prior to planting.

Willows are susceptible to livestock browse. Livestock must be excluded from all types of sites. Trees that provide dense shade or may uproot and topple over should be removed prior to the planting date.

All work will begin at the bottom of the slope and proceed upgrade. The vertical spacing between trenches on most sites should be 4 to 6 feet. Prior to digging the trench, stakes should be driven on the contour. They should be spaced 18 inches apart and have 6 inches exposed above the grade. The wattles are laid end to end and overlapped in the trench. Alternating between trench stakes, drive shorter stakes into the bundles to anchor them in place. Cover material should be taken from up slope. When completed, about 10% of the bundle should be exposed. A completed contour should resemble a slight terrace. Walking on the wattles while installing the adjacent above slope wattle enhances success of the process.

Installation can be done anytime from late fall to early spring, if the soil is not frozen or too wet. Planting should be done as soon as possible after delivery of the wattles. Keep them damp and protected from direct sunlight and heat. The formation of roots and initiation of topgrowth should occur within 30 days under optimum temperature and moisture conditions.

Maintenance: Periodic inspection should be scheduled to determine maintenance requirements. Some problems that may occur are failure of the wattle to sprout, washed out wattles, and new gully formation. Deficiencies whether engineering failure or absence of living plant material, should be repaired or replaced immediately or at the first window of opportunity.

CLUSTER R. BELCHER
Plant Materials Specialist
November 27, 1989

USDA - SOIL CONSERVATION SERVICE

PLANTING GUIDE

Dwarf Willow
(Salix cottetii Kerner)

Salix x cottetii
BANKERS WILLOW

Description: Dwarf willow is a fast growing, dense shrub, seldom exceeding eight feet in height. The native habitat of dwarf willow is the Alpine region of western Europe. The slender stems tend to be prostrate. Leaves are dark green in color, thick and ovate to linear shaped. Mature leaves are three to five inches long.

'Bankers' is a natural hybrid from a cross of Salix retusa and S. nigricans. Its height seldom exceeds six feet and this is the usual lateral spread. The stems tend to interlock and in moist soil readily form roots at the buds.

Adaptation: 'Bankers' is climatically adapted to the Appalachian region of the northeastern states. It is best adapted to wet sites subject to periodic flooding. Frequent wetting of the soil is essential for gravelly sites. Bankers is moderately shade tolerant

Wattle Construction: Wattles are prepared by cutting young or mature branches from healthy willow plants. Branches should be separated into groups of somewhat equal length. Bundles, called wattles are constructed by placing the branches alternately butt to tip. This process will form a cigar shaped wattle. Completed wattles should be 4 to 6 inches in diameter and vary from 4 to 7 feet in length. They should be loosely secured with twine or other suitable binding material every 6 inches of length. Normally, wattles will arrive at the site already prepared. They can be prepared locally, whenever, suitable plant material is available at the site.

Establishment:

On cut and fill slopes, shaping of the grade may be necessary. If the slope is relatively unstable, reinforcing engineering structure may be required at the base. Water should be diverted to prevent any overland flow onto the

slope. Cut or fill slopes are more likely to succeed than streambanks.

Streambanks that are eroding, undercut or have steep slopes may need to be regraded prior to planting.

Willows are susceptible to livestock browse. Livestock must be excluded from all types of sites. Trees that provide dense shade or may uproot and topple over should be removed prior to the planting date.

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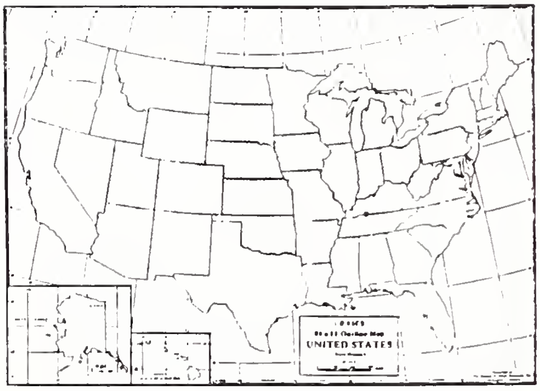
Plant Materials Specialist
November 27, 1989

Sandbar Willow

Salix exigua Nutt.

Family: Willow (Salicaceae) **April-June**

Field Marks: This willow is distinguished by the fewer number of teeth along the margins of the leaves.



Local Notes:

Habitat: Along streams, sandbars, frequently forming thickets.

Habit: Tree up to 25 feet tall, with an irregular crown.

Bark: Gray, furrowed, broken into rough scales.

Leaves: Alternate, simple, very long and narrow, pointed at the tip, tapering to the base, with widely spaced teeth, usually smooth at maturity, up to 4 inches long, less than 1/2 inch broad.

Flowers: Many in elongated spikes, the male and female flowers borne separately on separate plants.

Sepals: 0.

Petals: 0.

Stamens: 2.

Pistils: Ovary 1.

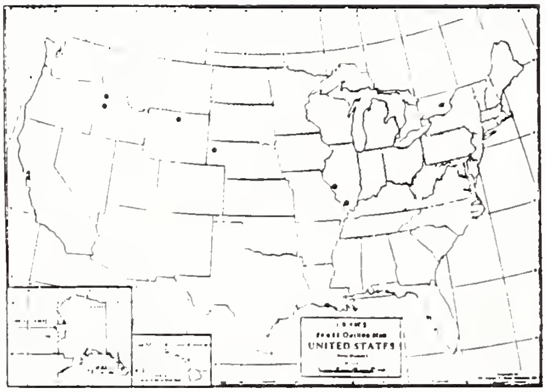
Fruits: Capsules flask-shaped, smooth or silky, brownish, up to 1/8 inch long.

Pussy Willow

Salix discolor Muhl.

Family: Willow (Salicaceae) **April-May**

Field Marks: The distinguishing features of the pussy willow are the broadly elliptic leaves that are usually rounded at the base and white but smooth on the lower surface.



Local Notes:

Habitat: Marshes, bottomland woods.

Habit: Shrub or small tree up to 20 feet tall.

Stems: Brown, hairy when young, becoming smooth.

Leaves: Alternate, simple, broadly elliptic, pointed at the tip, tapering or rounded at the base, finely toothed, smooth, white on the lower surface, up to 1 1/2 inches long.

Flowers: Many crowded into dense, cylindrical spikes up to 3 inches long, the male and female flowers in different spikes, each flower tiny, subtended by 1 bract.

Sepals: 0.

Petals: 0.

Stamens: 2.

Pistils: Ovary 1.

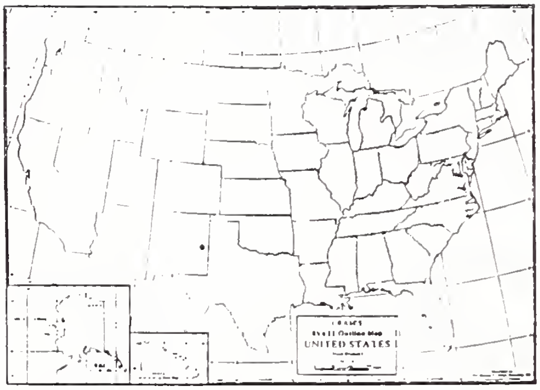
Fruits: Capsules long-tapering, gray-hairy, up to 1/2 inch long.

Black Willow

Salix nigra Marshall

Family: Willow (Salicaceae) **April-May**

Field Marks: Black willow is distinguished by its narrow leaves, green on the lower surface, and the presence of heart-shaped stipules.



Local Notes:

Habitat: Along streams, marshes, swamps, around lakes and ponds.

Habit: Tree up to 90 feet tall, usually round-topped.

Bark: Rough, furrowed, forming elongated, vertical, rather tight scales.

Leaves: Alternate, simple, narrowly lanceolate, pointed at the tip, rounded or tapering to the base, finely toothed, smooth, green on both surfaces, up to 6 inches long; stipules present, heart-shaped.

Flowers: Many borne in slender, elongated spikes; the male and female flowers borne in separate spikes on separate plants.

Sepals: 0.

Petals: 0.

Stamens: 3-7.

Pistils: Ovary 1.

Fruits: Capsules flask-shaped, reddish brown, up to 1/8 inch long.

PLANTS FOR CONSERVATION IN THE NORTHEAST
USDA - SOIL CONSERVATION SERVICE

CONSERVATION PLANT SHEET NE-82

REDOSIER DOGWOOD
(*Cornus sericea* ssp. *sericea*)

Plant Type: Native woody shrubs.

Seeds Per Pound: 18,500

Uses: The primary use of this species is for streambank protection. It can be planted alone or with other species, such as willows. Other beneficial uses are for fish and wildlife habitat improvement, windbreaks, slope stabilization, borders, and as ornamentals.

Description: Redosier dogwood is a large shrub, often 6-9 feet in height. The growth habit is upright rounded, but where stems are in contact with the ground, roots are formed. This behavior creates thickets. This dogwood has bright red stems in the fall, winter and early spring, which turn greenish in the summer. It also has white pith, dark green ovate leaves, white flowers, and whitish colored fruit.

Adaptation: Redosier dogwood is adapted from Ohio to Maine and south to northern Virginia and New Jersey. It performs best in soils that are moist, somewhat poorly drained, moderately acidic to neutral, and in areas that have medium to coarse soils. It is tolerant of some shade but not of droughty conditions.

Cultivars: 'Ruby' redosier dogwood was released in 1988 from the Big Flats, New York Plant Materials Center.

Sources: Foundation stock can be obtained from the Big Flats, New York Plant Materials Center. Rooted cuttings are available from commercial nurseries.

Establishment: Streambanks that have steep slopes must first be graded. The slope should be 1:1 or flatter. Any trees considered unstable should be removed. One year old rooted cuttings should be used for planting. Plant in early spring, preferably before May. Do not plant after June 1. Plant the cuttings two feet apart for streambank erosion control, four to six feet apart for wildlife habitat. Establishment with other species, such as willow and other riparian species, is a good practice. On sites with banks that may become dry over the summer, utilize redosier dogwood next to the water, with willows above. Immediately after planting, grasses and legumes may be planted to provide initial stabilization. After 2 or 3 years the

dogwoods will become effective. 'Ruby' is highly subject to livestock browsing. In order to ensure survival, fencing must be incorporated into the plan.

Rooted cuttings are grown from hardwood taken in January, allowed to develop callus in a refrigerated storage, and planted in mid-May in well drained soil 2 inches apart. The cuttings should be 1/4-1/2 inch in diameter and 9 to 12 inches long. They should be planted with 2 inches above ground level.

Management: Erosion is a continuous process and, because of this, careful management is required at these streambank plantings. These areas should be examined each spring after the major runoff period has ended. Areas where vegetation has been destroyed must be immediately replaced with new plants. If any mechanical measures are being used to prevent erosion, they must be maintained to prevent any more damage.

Disease: 'Ruby' redosier dogwood does not have many problems with disease or insect pests. There has been some problem with cicadas stinging the stems. Lesions and cankers may also occur. However, these are not pathogenic and are thought to just be the tree's reaction to injury.

Practice Application: Channel Vegetation (322), Critical Area Planting (342), Hedgerow Planting (422), Recreation Area Improvement (562), Streambank and Shoreline Protection (580), Streamchannel Stabilization (584), Wetland Development or Restoration (657), Wildlife Upland Habitat Management (645).

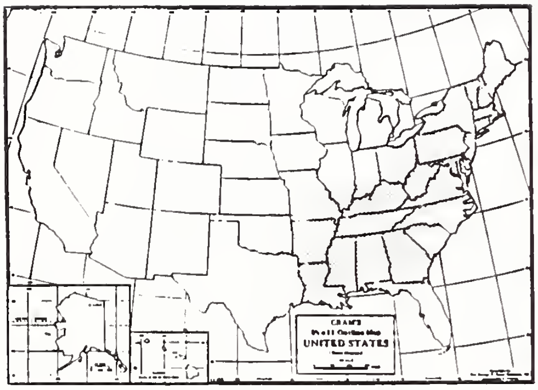
July 1993

Hazel Alder

Alnus serrulata (Ait.) Willd.

Family: Birch (Betulaceae) **March-April**

Field Marks: This alder has woody "cones" up to 1 inch long and wingless seeds.



Local Notes:

Habitat: Along streams, wet meadows.

Habit: Shrub with several stems.

Stems: Dark gray to black, up to 15 feet tall; the twigs usually rusty-hairy early in the season.

Leaves: Alternate, simple, ovate to obovate, pointed or rounded at the tip, rounded or nearly heart-shaped at the base, sharply toothed, hairy on the veins on the lower surface of the leaves.

Flowers: Male and female flowers borne separately but on the same plant, appearing before the leaves unfold; the male in slender, drooping spikes up to 3 inches long; the female in erect, oblong "cones" less than 1 inch long.

Sepals: 4, minute, present only in the male flowers.

Petals: 0.

Stamens: 4.

Pistils: Styles 2.

Fruits: Woody, cone-like, up to 1 inch long, containing several nut-like seeds; the seeds shiny, obovoid, up to 1/8 inch long, wingless.

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Engineering Field Handbook

Chapter 16 Streambank and Shoreline Protection

Issued December 1996

Cover: Little Yellow Creek, Cumberland Gap National Park, Kentucky
(photograph by Robbin B. Sotir & Associates)

Preface

Chapter 16, Streambank and Shoreline Protection, is one of 18 chapters of the U.S. Department of Agriculture, Natural Resources Conservation Service, Engineering Field Handbook, previously referred to as the Engineering Field Manual. Other chapters that are pertinent to, and should be referenced in use with, Chapter 16 are:

Chapter 1:	Engineering Surveys
Chapter 2:	Estimating Runoff
Chapter 3:	Hydraulics
Chapter 4:	Elementary Soils Engineering
Chapter 5:	Preparation of Engineering Plans
Chapter 6:	Structures
Chapter 7:	Grassed Waterways and Outlets
Chapter 8:	Terraces
Chapter 9:	Diversions
Chapter 10:	Gully Treatment
Chapter 11:	Ponds and Reservoirs
Chapter 12:	Springs and Wells
Chapter 13:	Wetland Restoration, Enhancement, or Creation
Chapter 14:	Drainage
Chapter 15:	Irrigation
Chapter 17:	Construction and Construction Materials
Chapter 18:	Soil Bioengineering for Upland Slope Protection and Erosion Reduction

This is the second edition of chapter 16. Some techniques presented in this text are rapidly evolving and improving; therefore, additions to and modifications of chapter 16 will be made as necessary.

Acknowledgments

This chapter was prepared under the guidance of **Ronald W. Tuttle,** national landscape architect, United States Department of Agriculture, Natural Resources Conservation Service (NRCS), and **Richard D. Wenberg,** national drainage engineer (retired).

Robbin B. Sotir & Associates, Marietta, Georgia, was a major contributor to the inclusion of soil bioengineering and revision of the chapter. In addition to authoring sections of the revised manuscript, they supplied original drawings, which were adapted for NRCS use, and photographs.

Walter K. Twitty, drainage engineer (retired), NRCS, Fort Worth, Texas, and **Robert T. Escheman,** landscape architect, NRCS, Somerset, New Jersey, served a coordination role in the review and revision of the chapter. **Carolyn A. Adams,** director, Watershed Science Institute, NRCS, Seattle, Washington; **Leland M. Saele,** design engineer; **Gary E. Formanek,** agricultural engineer; and **Frank F. Reckendorf,** sedimentation geologist (retired), NRCS, Portland, Oregon, edited the manuscript to extend its applicability to most geographic regions. In addition these authors revised the manuscript to reflect new research on stream classification and design considerations for riprap, dormant post plantings, rootwad/boulder revetments, and stream barbs. **H. Wayne Everett,** plant materials specialist (retired), NRCS, Fort Worth, Texas, supplied the plant species information in the appendix. **Mary R. Mattinson,** editor, **John D. Massey,** visual information specialist, and **Wendy R. Pierce,** illustrator, NRCS, Fort Worth, Texas, provided editing assistance and desktop publishing in preparation for printing.

Chapter 16 Streambank and Shoreline Protection

Contents:

650.1600 Introduction

(a) Purpose and scope

Streambank and shoreline protection consists of restoring and protecting banks of streams, lakes, estuaries, and excavated channels against scour and erosion by using vegetative plantings, soil bioengineering, and structural systems. These systems can be used alone or in combination. The information in chapter 16 does not apply to erosion problems on ocean fronts, large river and lake systems, or other areas of similar scale and complexity.

(b) Categories of protection

The two basic categories of protection measures are those that work by reducing the force of water against a streambank or shoreline and those that increase their resistance to erosive forces. These measures can be combined into a system.

Stormwater reduction or retention methods, grade reduction, and designs that reduce flow velocity fall into the first category of protection. Examples include permeable fence design, tree or brush revetments, jacks, groins, stream jetties, barbs, drop structures, increasing channel sinuosity, and log, rootwad, and boulder combinations. The second category includes channels lined with grass, concrete, riprap, gabions, cellular concrete, and other revetment designs. These measures can be used alone or in combination. Most designs that employ brushy vegetation, e.g., soil bioengineering, either alone or in combination with structures, protect from erosion in both ways.

Revetment designs do not reduce the energy of the flow significantly, so using revetments for spot protection may move erosion problems downstream or across the stream channel.

(c) Selecting streambank and shoreline protection measures

This document recognizes the need for intervention into stream corridors to affect rehabilitation; however, it is also acknowledged that this should be done on a selective basis. When selecting a site or stream reach for treatment, it is most effective to select areas within relatively healthy systems. Projects planned and installed in this context are more likely to be successful, and it is often critically important to prevent the decline of these healthier systems while an opportunity remains to preserve their biological diversity. Rehabilitation of highly degraded systems is also important, but these systems often require substantial investment of resources and may be so modified that partial success is often a realistic goal.

After deciding rehabilitation is needed, a variety of remedies are available to minimize the susceptibility of streambanks or shorelines to disturbance-caused erosive processes. They range from vegetation-oriented remedies, such as soil bioengineering, to engineered grade stabilization structures (fig. 16–1). In the recent past, many organizations involved in water resource management have given preference to engineered structures. Structures may still be viable options; however, in a growing effort to restore sustainability and ensure diversity, preference should be given to those methods that restore the ecological functions and values of stream or shoreline systems.

As a first priority consider those measures that

- are self sustaining or reduce requirements for future human support;
- use native, living materials for restoration;
- restore the physical, biological, and chemical functions and values of streams or shorelines;
- improve water quality through reduction of temperature and chronic sedimentation problems;
- provide opportunities to connect fragmented riparian areas; and
- retain or enhance the stream corridor or shoreline system.

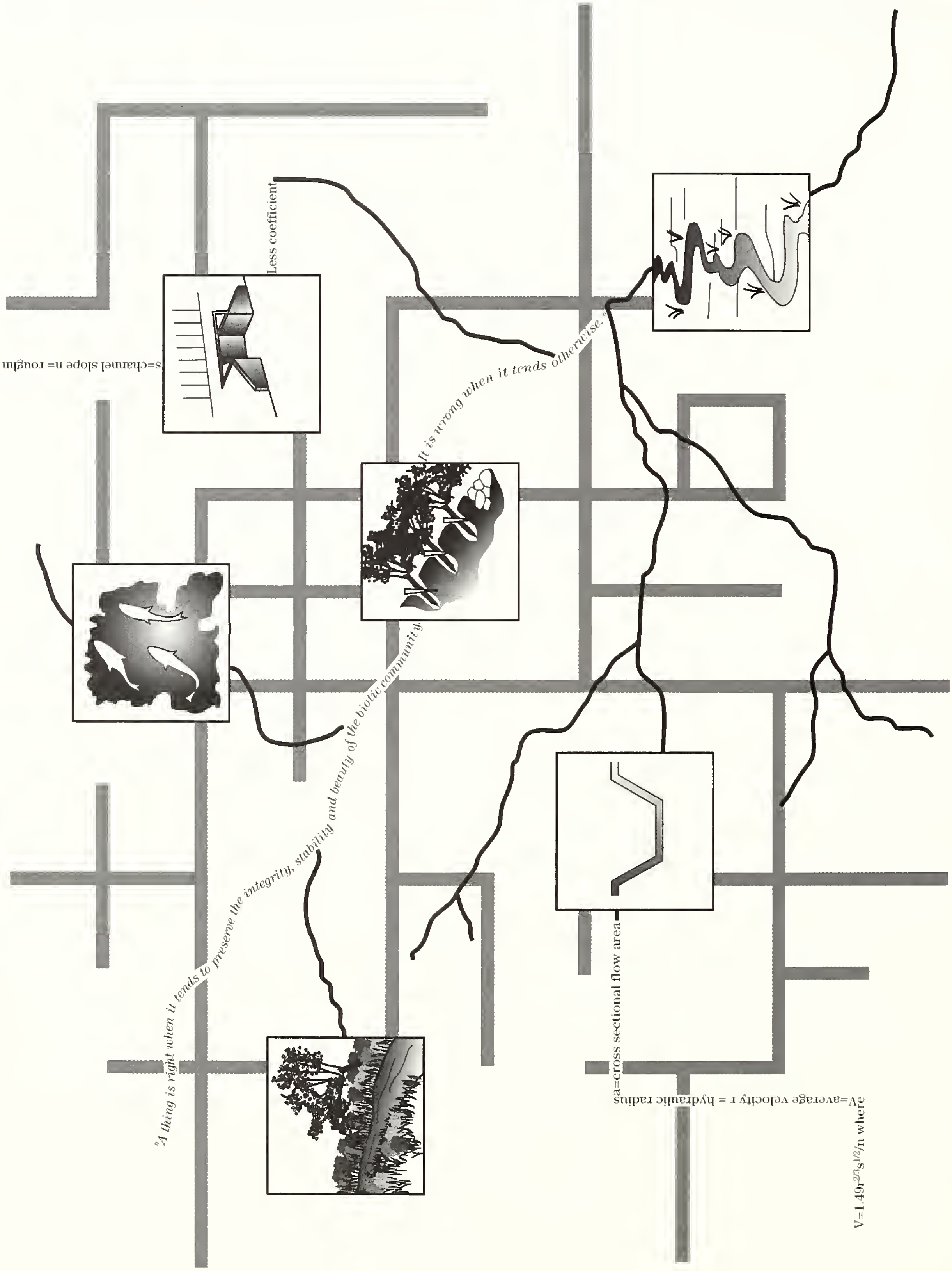


Figure 16–1 Appropriate selection and application of streambank or shoreline protection measures should vary in response to specific objectives and site conditions (Aldo Leopold)

650.1601 Streambank protection

(a) General

The principal causes of streambank erosion may be classed as geologic, climatic, vegetative, and hydraulic. These causes may act independently, but normally work in an interrelated manner. Direct human activities, such as channel confinement or realignment and damage to or removal of vegetation, are major factors in streambank erosion.

Streambank erosion is a natural process that occurs when the forces exerted by flowing water exceed the resisting forces of bank materials and vegetation. Erosion occurs in many natural streams that have vegetated banks. However, land use changes or natural disturbances can cause the frequency and magnitude of water forces to increase. Loss of streamside vegetation can reduce resisting forces, thus streambanks become more susceptible to erosion. Channel realignment often increases stream power and may cause streambeds and banks to erode. In many cases streambed stabilization is a necessary prerequisite to the placement of streambank protection measures.

(b) Planning and selecting streambank protection measures

The list that follows, although not exhaustive, includes data commonly needed for planning purposes.

(1) Watershed data

When analyzing the source of erosion problems, consider the stream as a system that is affected by watershed conditions and what happens in other stream reaches. An analysis of stream and watershed conditions should include historical information on land use changes, hydrologic conditions, and natural disturbances that might influence stream behavior. It should anticipate the changes most likely to occur or that are planned for the near future:

- Climatic regime.
- Land use/land cover.
- History of land use, prior stream modifications, past stability problems, and previous treatments.
- Projected development over anticipated project life.

(2) Causes and extent of erosion problems

- If bank failure problems are the result of widespread bed degradation or headcutting, determine what triggered the problem.
- If bank erosion problems are localized, determine the cause of erosion at each site.

(3) Hydrologic/hydraulic data

- Flood frequency data (if not available, estimate using regional equations or other procedures).
- Estimates of stream-forming flow at 1- to 2-year recurrence interval and flow velocities.
- Estimates of width and depth at stream-forming flow conditions.
- Channel slope, width, depth, meander wavelength, and shape (width/depth, wetted perimeter).
- Sediment load (suspended and bedload).
- Water quality.

(4) Stream reach characteristics

- Soil and streambank materials at site.
- Potential streambank failures.
- Vegetative condition of banks.
- Channel alignment.
- Present stream width, depth, meander amplitude, belt width, wavelength, and sinuosity to determine stream classification.
- Identification of specific problems arising from flow deflection caused by sediment buildup, boulders, debris jams, bank irregularities, or constrictions.
- Bed material d_{50} based on a pebble count.
- Quality, amount, and types of terrestrial and aquatic habitat.
- Suspended load and bedload as needed, to determine if incoming sediment load can be transported through the restored reach.
- When selecting protective measures, analyze the needs of the entire watershed, the effects that stream protection may have on other reaches, surrounding wetlands, the riparian corridor, terrestrial habitat, aquatic habitat, water quality, and aesthetics. Reducing runoff and soil loss from the upland portions of the watershed using sound land treatment and management measures normally makes the streambank protection solution less expensive and more durable.

(5) Stream classification

Stream classification has evolved significantly over the past 100 years. William Davis (1899) first divided streams into three stages as youthful, mature and old age. Streams were later classified by their pattern as straight, meandering, or braided (Leopold & Wolman, 1957) or by stability and mode of sediment transport (Schumm, 1963 and 1977). Although all these systems served their intended purposes, they were not particularly helpful in establishing useful criteria for streambank protection and design. Rosgen (1985) developed a stream classification system that categorizes essentially all types of stream channels on the basis of measured morphological features. This system has been updated several times (Rosgen, 1992) and has broad applicability for communication among users and to predict a stream's behavior based on its appearance.

Predicting a stream's behavior based on appearance is also a feature of the Schumm, Harvey, and Watson (1984) channel evolution model developed for Oaklimeter Creek in Mississippi. This model discusses channel conditions extending from total disequilibrium to a new state of dynamic equilibrium. Such a model is useful in stream restoration work because streams can be observed in the field and their dominant process determined in the reach under consideration (i.e., active headcutting and transport of sediment, through aggradation and stabilization of alternate bars, and approaching a stage of dynamic equilibrium).

Rosgen's (1992) stream classification system goes beyond the channel evolution model as it is based on determining hydraulic geometry of stable stream reaches. This geometry is then extrapolated to unstable stream reaches to derive a template for potential channel design and reconstruction.

The present version of Rosgen's stream classification has several types (A, B, C, D, DA, E, F, and G), based on a hierarchical system. The first level of classification distinguishes between single or multiple thread channels. The streams are then separated based on degrees of entrenchment, width-to-depth ratio, and stream sinuosity. They are further subdivided by slope range and channel materials. Several stream subtypes are based on other criteria, such as average riparian vegetation, organic debris and channel blockages, flow regimes, stream size, depositional features, and meander pattern.

(6) Soils

A particular soil's resistance to erosion depends on its cohesiveness and particle size. Sandy soils have low cohesion, and their particles are small enough to be entrained by velocity flows of 2 or 3 feet per second. Lenses or layers of erodible material are frequent sources of erosion. Fines are selectively removed from soils that are heterogeneous mixtures of sand and gravel, leaving behind a layer of gravel that may protect or armor the streambed against further erosion. However, the hydraulic removal of fines and sand from a gravel matrix may cause it to collapse, resulting in sloughing of the streambank and its overlying material.

The resistance of cohesive soils depends on the physical and chemical properties of the soil as well as the chemical properties of the eroding fluid. Cohesive soils often contain montmorillonite, bentonite, or other expansive clays. Because unvegetated banks made up of expansive clays are subject to shrinkage during dry weather, tension cracks may develop parallel to and several feet below the top of the bank. These cracks may lead to slab failures on oversteepened banks, especially in places where bank support has been reduced by toe erosion. Tension cracks can also contribute to piping and related failures.

(7) Hydrologic, climatic, and vegetative conditions

Stream erosion is largely a function of the magnitude and frequency of flow events. Flow duration is of secondary importance except for flows that exceed stream-forming flow stage for extended periods. A streambank's position (outside curve or inside) can also be a major factor in determining its erosion potential.

Watershed changes that increase magnitude and frequency of flooding, such as urbanization, deforestation, and increased surface runoff, contribute to streambank erosion. Associated changes, such as loss of streamside vegetation from human or animal trampling, often compound the streambank erosion effect.

In cold climates where streams normally freeze or partly freeze during winter, erosion caused by ice is an additional problem. Streambanks are affected by ice scour in several ways:

- Streambanks and associated vegetation can be forcibly damaged during freezing or thawing action.

- Floating ice can cause gouging of streambanks.
- Acceleration of flow around and under ice rafts can cause damage to streambanks.

Erosion from ice may be minimized or reduced by vegetation for the following reasons:

- Streambank vegetation reduces damaging cycles of freeze-thaw by maintaining the temperature of bank materials, thus preventing ice from forming and encouraging faster thawing.
- Vegetation tends to be flexible and absorbs much of the momentum of drifting ice.
- Vegetation helps protect the bank from ice damage.
- Woody vegetation has deeply embedded roots that reinforce soils.
- Deeply rooted, woody vegetation helps to control erosion by adding strength to streambank materials, increasing flow resistance, reducing flow velocities in the vicinity of the bank, and retarding tension crack development.

(8) Hydraulic data

Stream power is a function of velocity, flow depth, and slope. Channelization projects that straighten or enlarge channels often increase one or more of these factors enough to cause widespread erosion and associated problems, especially if soils are easily erodible.

Headcuts often develop in the modified reach or at the transition from the modified reach to the unaltered reach. They move upstream, causing bed erosion and bank failure on the main stream and its tributaries. Returning the stream to its former meander geometry is generally the most reliable way to stop headcuts or prevent their development. Installing grade control structures that completely cross a stream and act as a very low head dam may initiate other channel instabilities by:

- inducing bank erosion around the ends of the structure;
- raising flood levels and causing out-of-bank flows to erode new channels;
- trapping sediment, thus decreasing channel capacity, inducing bank erosion and flood plain scour; and
- increasing width-to-depth ratio with subsequent lateral migration, increased bank erosion, and increased bar deposition or formation.

Grade control structures should be designed to maintain low channel width-to-depth ratios, maintain the sediment transport capacity of the channel, and provide for passing a wide range of flow velocities without creating backwater and causing sediment deposition. Vortex rock weirs, "W" rock weirs, and other rock/boulder structures that protect the channel without creating backwater should be considered instead of small rock and log dams.

Local obstructions to flow, channel constrictions, and bank irregularities cause local increases in the energy slope and create secondary currents that produce accelerations in velocity sufficient to cause localized streambank erosion problems. These localized problems often are treated best by eliminating the source of the problem and providing remedial bank protection. However, secondary cross currents are also a natural feature around the outside curves of meanders, and structural features may be required to modify these cross currents.

Streamflows that transport sustained heavy loads of sediment are less erosive than clear flows. This can easily be seen where dams are constructed on large sediment-laden streams. Once a dam is operational, the sediment drops out into the reservoir pool, so the water leaving the structure is clear. Several feet of degradation commonly occurs in the reach below the dam before an armor layer develops or hydraulic parameters are sufficiently altered to a stable grade. In watersheds that have high sediment yields, conservation treatments that significantly reduce sediment loads can trigger stream erosion problems unless runoff is also reduced.

(9) Habitat characteristics

The least-understood aspect of designing and analyzing streambank protection measures is often the impact of the protective measures on instream and riparian habitats. Commonly, each stage of the life cycle of aquatic species requires different habitats, each having specific characteristics. These diverse habitats are needed to meet the unique demands imposed by spawning and incubation, summer rearing, and overwintering. The productivity of most aquatic systems is directly related to the diversity and complexity of available habitats.

Fish habitat structures are commonly an integral part of stream protection measures, but applicability of habitat structures varies by classified stream type. Work by Rosgen and Fittante (1992) resulted in a guide for evaluating suitability of various proposed fish habitat structures for a wide range of morphological stream types. They divide structures into those for rearing habitat enhancement and those for spawning habitat enhancement. The structures for rearing habitat enhancement include low stage check dam, medium stage check dam, boulder placement, bank-placed materials, single wing deflector, channel constrictor, bank cover, floating log cover, submerged shelter, half log cover, and migration barrier. U-shaped gravel traps, log sill gravel traps, and gravel placement are for spawning habitat enhancement.

Since a multitude of interrelated factors influence the productivity of streams, the response of fish and wildlife populations to changes in habitat is often difficult to predict with confidence.

(10) Environmental data

Environmental goals should be set early in the planning process to ensure that full consideration is given to ecological stability and productivity during the selection and design of streambank protection measures. Special care should be given to consideration of terrestrial and aquatic habitat benefits of alternative types of protection and to maintenance needs on a site specific basis.

In general, the least disturbance to the existing stream system during construction and maintenance produces the greatest environmental benefits. Damages to the environment can be limited by:

- Using small equipment and hand labor.
- Limiting access.
- Locating staging areas outside work area boundaries.
- Avoiding or altering construction procedures during critical times, such as fish spawning or bird nesting periods.
- Coordinating construction on a stream that involves more than one job or ownership.
- Adopting maintenance plans that maximize riparian vegetation and allow wide, woody vegetative buffers.
- Scheduling construction activities to avoid expected peak flood season(s).

(11) Social and economic factors

Initial installation cost and long-term maintenance are factors to be considered when planning streambank and shoreline protection. Other factors include the suitability of construction material for the use intended, the cost of labor and machinery, access for equipment and crews at the site, and adaptations needed to adjust designs to special conditions and the local environment.

Some protection measures seem to have apparent advantages, such as low cost or ease of construction, but a more expensive alternative might best meet planned objectives when maintenance, durability of material, and replacement costs are considered. Effect upon resources and environmental values, such as aesthetics, wildlife habitat, and aquatic requirements, are also integral factors.

The need for access to the stream or shoreline and the effects of protection measures upon adjacent property and land uses should be analyzed.

Minor protective measures can be installed without using contract labor or heavy equipment. However, many of the protective measures presented in this chapter require evaluation, design, and implementation to be done by a knowledgeable interdisciplinary team because precise construction techniques and costly construction materials may be required.

(c) Design considerations for streambank protection

(1) Channel grade

The channel grade may need to be controlled before any permanent type of bank protection can be considered feasible unless the protection can be safely and economically constructed to a depth well below the anticipated lowest depth of bed scour. Control can be by natural or artificial means. Reconstructing stream channels to their historical stream type (i.e., stream geometry) has been successfully used to achieve grade control. Artificial measures typically include rock, gabions and reinforced concrete grade control structures.

(2) Discharge frequency

Maximum floods are rarely used for design of streambank protection measures. The design flood frequency should be compatible with the value or safety of the property or improvements being protected, the repair cost of the streambank protection, and the sensitivity and value of ecological systems within the planning unit. Bankfull discharge (stream-forming flow) of natural streams tends to have a recurrence interval of 1 to 2 years based on the annual flood series (Leopold and Rosgen, 1991). The discharge at this frequency is commonly used as a design discharge for stream restoration (Rosgen, 1992). For modified streams, the 1- to 2-year frequency discharge is also useful for design discharge because it is the flow that has the most impact upon the stability of the stream channel.

(3) Discharge velocities

Where the flow entering the section to be protected carries only clay, silt, and fine sand in suspension, the maximum velocity should be limited to that which is nonscouring on the least resistant material occurring in any appreciable quantity in the streambed and bank. The minimum velocity should be that required to transport the suspended material. The depth-area-velocity relationship of the upstream channel should be maintained through the protected reach. Where the flow entering the section is transporting bedload, the minimum velocity should be that which will transport the entering bedload material through the section.

The minimum design velocity should also be compatible with the needs of the various fish species present or those targeted for recovery. Velocity changes can reduce available habitat or create physical barriers that restrict fish passage. Further information on fish habitat is available in publications cited in the reference section.

Streambank protection measures on large, wide channels most likely will not significantly change streamflow velocity. On smaller streams, however, the protective measures can influence the velocity throughout the reach.

In calculating these velocities, the Manning's n values selected should represent the stream condition after the channel has matured, which normally requires several years. Erosion or sedimentation may occur if this is not anticipated.

(4) Freeboard

Freeboard should be provided to prevent overtopping of the revetment at curves and other points where high velocity flow contacts the revetment. In these areas a potential supercritical velocity can set up waves, and the climb on sloping revetments may be appreciable. Because an accurate method to determine freeboard requirements is not available for sloping revetments in critical zones, the allowance for freeboard should be based on sound judgment and experience. Under similar conditions, the freeboard required for a sloping revetment is always greater than that for a vertical revetment.

(5) Alignment

Changes in channel alignment affect the flow characteristics through, above, and below the changed reach. Straightening without extensive channel hardening does not eliminate a stream's tendency to meander. An erosion hazard may often develop at both ends of the channel because of velocity increases, bar formations, and current direction changes. Changes in channel alignment are not recommended unless the change is to reconstruct the channel to its former meander geometry.

Alignment of the reach must also be carefully considered in designing protective measures. Because of major changes in hydraulic characteristics, streambanks for channels having straight alignment generally require a continuous scour-resistant lining or revetment. To prevent scour by streamflow as the stream attempts to recreate its natural meander pattern, most banks must be sloped to a stable grade before the lining is applied. For nonrigid lining, the slope must be flat enough to prevent the lining material from sliding.

Curved revetments are subjected to increased forces because of the secondary currents acting against them. More substantial and permanent types of construction may be needed on curved channel sections because streambank failures at these vulnerable points could result in much greater damage than that along unobstructed straight reaches of channel.

(6) Stream type and hydraulic geometry

Stream rehabilitation should be considered in the context of the historically stable stream type and its geometry. If stream modification has caused shortened meander wavelength, amplitude, and radius of curvature, the stream being treated might be best stabilized by restoring the historical geometry. The width-to-depth ratio of the stream being treated may be too high to transport the sediment load, and a lower ratio may be needed in the design channel.

(7) Sediment load and bed material

To determine the potential for stream aggradation, the sediment load (bedload and suspended) for storm and snowmelt runoff periods must frequently be determined before reconstruction. The size distribution of the streambed and bar material also should be determined. These measurements are important above and below the reconstruction reach under consideration as well as in the main tributary streams above the reach. This information is used with appropriate shear stress equations to determine the size of material that would be entrained at bankfull discharge (stream-forming flow) for both the tributary streams and in the restored reach. The sediment transport rate must be sufficient to prevent aggradation of the newly restored channel. As shown by studies in Colorado (Andrews, 1983) on gravelbed rivers, it is anticipated that particles as large as the median diameter of the bed surface will be entrained by discharge equal to the bankfull stage (stream-forming flow) or less.

(8) Protection against failure

Measures should be designed to provide against loss of support at the revetment's boundaries. This includes upstream and downstream ends, its base or toe, and the crest or top.

(9) Undermining

Undermining or scouring of the foundation material by high velocity currents is a major cause of bank protection failure. In addition to protecting the lowest expected stable grade, additional depth must be provided to reach a footing that most likely will not be scoured out during floods or lose its stability through saturation. Deep scour can be expected where construction is on an erodible streambed and high velocity currents flow adjacent to it.

Methods used to provide protection against undermining at the toe are:

- Extending the toe trench down to a depth below the anticipated scour and backfilling with heavy rock.
- Anchoring a heavy, flexible mattress to the bottom of the revetment, which at the time of installation will extend some distance out into the channel. This mattress will settle progressively as scour takes place, protecting the revetment foundation.
- Installing a massive toe of heavy rock where excavation for a deep toe is not practical. This allows the rock forming the toe to settle in place if scour occurs. However, because of the forces of flow, the settlement direction of the rock is not always straight down.
- Driving sheet piling to form a continuous protection for the revetment foundation. Such piling should be securely anchored against lateral pressures. To provide for a remaining embedment after scour, piling should be driven to a depth equal to about twice the exposed height.
- Installing toe deflector groins to deflect high velocity currents away from the toe of the revetment.
- Installing submerged vanes to control secondary currents.

Since most of these measures have direct impacts on aquatic habitat and other stream functions and values, their use should be considered carefully when planning a streambank protection project.

(10) Ends of revetment

The location of the upstream and downstream ends of revetments must be selected carefully to avoid flanking by erosion. Wherever possible, the revetment should tie into stable anchorage points, such as bridge abutments, rock outcrops, or well-vegetated stable sections. If this is not practical, the upstream and downstream ends of the revetment must be positioned well into a slack water area along the bank where bank erosion is not a problem.

(11) Debris removal

Streambank protection may require the selective removal or repositioning of debris, such as fallen trees, sediment bars, or other obstructions. Because logs and other woody debris are the major habitat-forming components in many stream systems, a plan for debris removal should be developed in consultation with qualified fish and wildlife specialists. Small accumulations of debris and sediment generally do not cause problems and should be left undisturbed.

When planning streambank stabilization work, select access routes for equipment that minimize disturbance to the flood plain and riparian areas. All debris removal, grading, and material delivery and placement should be accomplished in a manner that uses the smallest equipment feasible and minimizes disturbance of riparian vegetation. Excavated material should be disposed of in such a way that it does not interfere with overbank flooding, flood plain drainage, or associated wetland hydrology. In high velocity streams it may be necessary to remove floating debris selectively from flood-prone areas or anchor it so that it will not float back into the channel.

Sediment bars, snags, trees, and other debris drifts that create secondary currents or deflect flow toward the banks may require selective removal or relocation in the stream channel. The entire plant structure does not always need to be dislodged when considering the removal of trees and snags; rooted stumps should be left in place to prevent erosion. Isolated or single logs that are embedded, lodged, or rooted in the channel and not causing flow problems should not be disturbed. Fallen trees may be used to construct bank protection systems. Trees and other large vegetation are important to aquatic, aesthetic and riparian habitat systems, and removal should be done judiciously and with great care.

(12) Vegetative systems

Vegetative systems provide many benefits to fish and wildlife populations as well as increasing the streambank's resistance to erosive forces. Vegetation near the channel provides shade to help maintain suitable water temperature for fish, provides habitat for wildlife and protection from predators, and contributes to aesthetic quality. Leaves, twigs, and insects drop into the stream, providing nutrients for aquatic life (fig. 16–2).

Figure 16–2 Vegetative system along streambank

Although woody brush is preferable for habitat reasons, suitable herbaceous ground cover can provide desirable bank protection in areas of marginal erosion. Perennial grasses and forbes, preferably those native to the area, should be used rather than annual grasses. Woody vegetation may also be used to control undesirable access to the stream.

Associated emergent aquatic plants serve multiple functions, including the protection of woody streambank or shoreline vegetation from wave or current wave action, which tend to undercut them.

Vegetation protects streambanks in several ways:

- Root systems help hold the soil particles together increasing bank stability.
- Vegetation may increase the hydraulic resistance to flow and reduce local velocities in small channels.
- Vegetation acts as a buffer against the hydraulic forces and abrasive effect of transported materials.
- Dense vegetation on streambanks can induce sediment deposition.
- Vegetation can redirect flow away from the bank.

(d) Protective measures for streambanks

Protective measures for streambanks can be grouped into three categories: vegetative plantings, soil bioengineering systems, and structural measures. They are often used in combination.

(1) Vegetative plantings

Conventional plantings of vegetation may be used alone for bank protection on small streams and on locations having only marginal erosion, or it may be used in combination with structural measures in other situations. Considerations in using vegetation alone for protection include:

- Conventional plantings require establishment time, and bank protection is not immediate.
- Maintenance may be needed to replace dead plants, control disease, or otherwise ensure that materials become established and self-sustaining.
- Establishing plants to prevent undercutting and bank sloughing in a section of bank below baseflow is often difficult.
- Establishing plants in coarse gravely material may be difficult.
- Protection and maintenance requirements are often high during plant establishment.

Woody vegetation, which is seeded or planted as rooted stock, is used most successfully above baseflow on properly sloped banks and on the flood plain adjacent to the banks. Vegetation should always be used behind revetments and jetties in the area where sediment deposition occurs, on the banks above baseflow, and on slopes protected by cellular blocks or similar type materials.

Many species of plants are suitable for streambank protection (see appendix 16B). Use locally collected native species as a first priority. Exotic or introduced species should be used only if there is no alternative. They should never be invasive species. Locally available erosion-resistant species that are suited to the soil, moisture, and climatic conditions of a particular site are desirable. Aesthetics may also play an important role in selecting plants for certain areas.

In many instances streambank erosion is accelerated by overgrazing, cultivating too close to the banks, or by overuse. In either case the treated area should be protected by adequate streamside buffers and appropriate management practices. If the stream is the source of livestock drinking water, access can be provided by establishing a ramp down to the water. Such ramps should be located where the bank is not steep and, preferably, in straighter sections or at the inside of curves in the channel where velocities are low. Providing watering facilities out of the channel (i.e., on the flood plain or terrace) for the livestock is often a preferred alternative to using ramps.

The visual impact, habitat value, and other environmental effects of material removal or relocation must also be considered before performing any work.

Protective measures reduce streambank erosion and prevent land losses and sediment damages, but do not directly stabilize the channel grade. However, if the channel is restored to a stable stream type, vegetative protective measures, such as soil bioengineering, can be used to stabilize the streambanks. Vegetation assists in bank stabilization by trapping sediment, reducing tractive stresses acting on the bank, redirecting the flow, and holding soil. The boundary shear stress provided by vegetation, however, is much less than that provided by structural elements.

(2) Soil bioengineering systems

Properly designed and constructed soil bioengineering systems have been used successfully to stabilize streambanks (figs. 16–3a, 16–3b, 16–3c, and 16–3d).

Soil bioengineering is a system of living plant materials used as structural components. Adapted types of woody vegetation (shrubs and trees) are initially installed in specified configurations that offer immediate soil protection and reinforcement. In addition, soil bioengineering systems create resistance to sliding or shear displacement in a streambank as they develop roots or fibrous inclusions. Environmental benefits derived from woody vegetation include diverse and productive riparian habitats, shade, organic additions to the stream, cover for fish, and improvements in aesthetic value and water quality.

Under certain conditions, soil bioengineering installations work well in conjunction with structures to provide more permanent protection and healthy function, enhance aesthetics, and create a more environmentally acceptable product. Soil bioengineering systems normally use unrooted plant parts in the form of cut branches and rooted plants. For streambanks, living systems include brushmattresses, live stakes, joint plantings, vegetated geogrids, branchpacking, and live fascines.

Major attractions of soil bioengineering systems are their natural appearance and function and the economy with which they can often be constructed. As discussed in chapter 18 of this Engineering Field Handbook, the work is normally done in the dormant months, generally September to March, which is the off season for many laborers. The main construction materials are live cuttings from suitable plant species. Species must be appropriate for the intended use and adapted to the site's climate and soil conditions.

Consult a plant materials specialist for guidance on plant selection. Ideally plant materials should come from local ecotypes and genetic stock similar to that within the vicinity of the stream. Species that root easily, such as willow, are required for measures, such as live fascines and live staking, or where unrooted cuttings are used with structural measures. Suitable plant materials are listed in appendix 16B. They may also be identified in Field Office Technical Guides for specific site conditions or by contacting Plant Materials Centers.

Many sites require some earthwork before soil bioengineering systems are installed. A steep undercut or slumping bank, for example, may require grading to a 3:1 or flatter slope. Although soil bioengineering systems are suitable for most sites, they are most successful where installed in sunny locations and constructed during the dormant season.

Rooted seedlings and rooted cuttings are excellent additions to soil bioengineering projects. They should be installed for species diversification and to provide habitat cover and food for fish and wildlife. Optimum establishment is usually achieved shortly after earth work, preferably in the spring.

Some of the most common and useful soil bioengineering structures for restoration and protection of streambanks are described in the following sections.

Figure 16–3a Eroding bank, Winooski River, Vermont, June 1938

Figure 16–3b Bank shaping prior to installing soil bioengineering practices, Winooski River, Vermont, September 1938

Figure 16–3c Three years after installation of soil bioengineering practices, 1941

Figure 16–3d Soil bioengineering system, Winooski River, Vermont, June 1993 (55 years after installation)

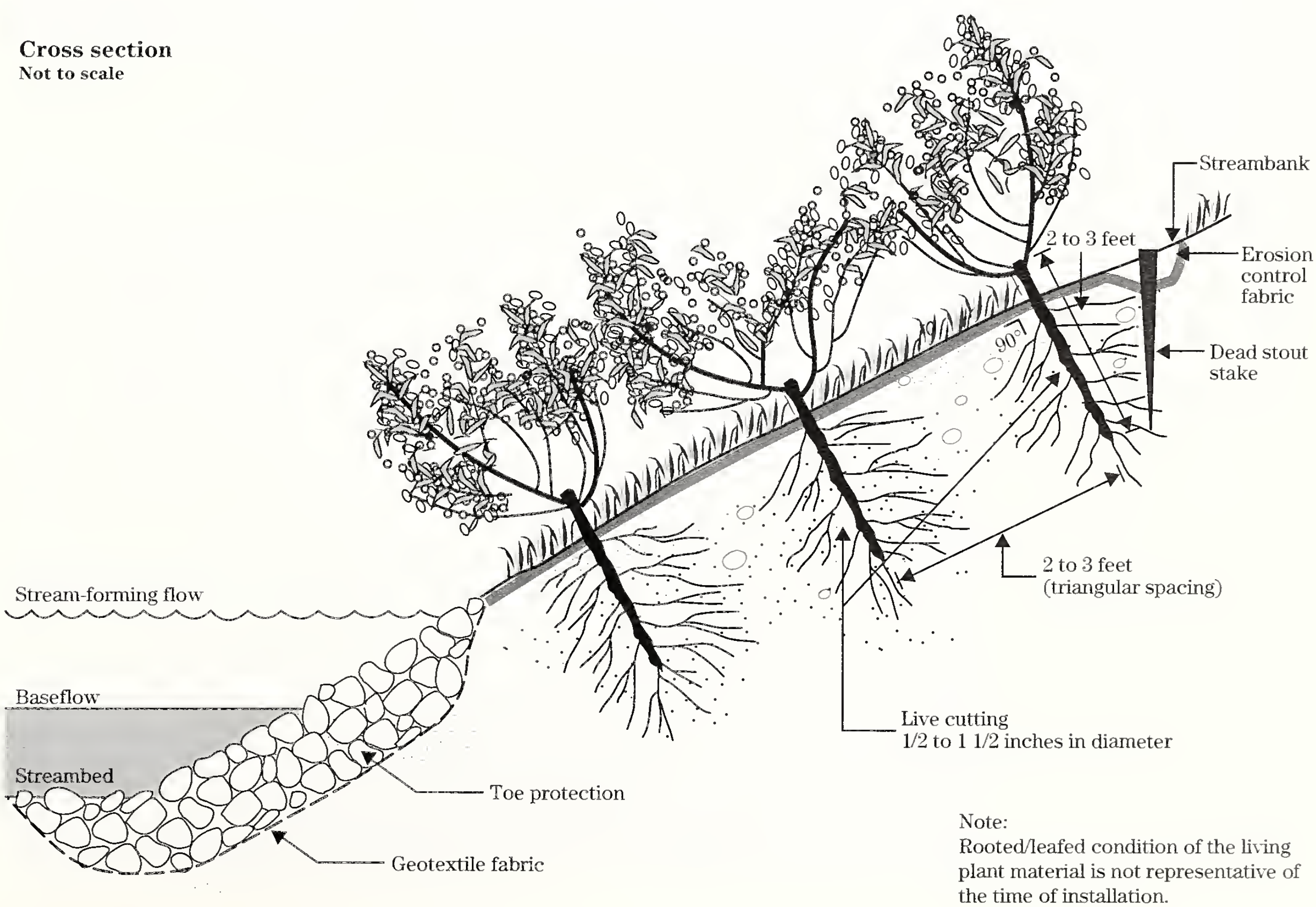
(i) ***Live stakes***—Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground (figs. 16–4 and 16–5). If correctly prepared, handled, and placed, the live stake will root and grow (fig. 16–6).

A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Most willow species root rapidly and begin to dry out a bank soon after installation.

Applications and effectiveness

- Effective streambank protection technique where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed.
- Appropriate technique for repair of small earth slips and slumps that frequently are wet.
- Can be used to peg down and enhance the performance of surface erosion control materials.
- Enhance conditions for natural colonization of vegetation from the surrounding plant community.
- Stabilize intervening areas between other soil bioengineering techniques, such as live fascines.
- Produce streamside habitat.

Figure 16–4 Live stake details



Construction guidelines

Live material sizes—The stakes generally are 0.5 to 1.5 inches in diameter and 2 to 3 feet long. The specific site requirements and available cutting source determine sizes.

Live material preparation

- The materials must have side branches cleanly removed with the bark intact.
- The basal ends should be cut at an angle or point for easy insertion into the soil. The top should be cut square.
- Materials should be installed the same day that they are prepared.

Installation

- Erosion control fabric should be placed on slopes subject to erosive inundation.
- Tamp the live stake into the ground at right angles to the slope and diverted downstream. The installation may be started at any point on the slope face.
- The live stakes should be installed 2 to 3 feet apart using triangular spacing. The density of the installation will range from 2 to 4 stakes per square yard. Site variations may require slightly different spacing.
- Placement may vary by species. For example, along many western streams, tree-type willow species are placed on the inside curves of point bars where more inundation occurs, while shrub willow species are planted on outside curves where the inundation period is minimal.
- The buds should be oriented up.
- Four-fifths of the length of the live stake should be installed into the ground, and soil should be firmly packed around it after installation.
- Do not split the stakes during installation. Stakes that split should be removed and replaced.
- An iron bar can be used to make a pilot hole in firm soil.
- Tamp the stake into the ground with a dead blow hammer (hammer head filled with shot or sand).

Figure 16–5 Prepared live stake (Robbin B. Sotir & Associates photo)

Figure 16–6 Growing live stake

(ii) Live fascines—Live fascines are long bundles of branch cuttings bound together in cylindrical structures (fig. 16–7). They should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow sliding.

Applications and effectiveness

- Apply typically above bankfull discharge (stream-forming flow) except on very small drainage area sites (generally less than 2,000 acres).
- Effective stabilization technique for streambanks. When properly installed, this system does not cause much site disturbance.
- Protect slopes from shallow slides (1 to 2 foot depth).
- Offer immediate protection from surface erosion.
- Capable of trapping and holding soil on a streambank by creating small dam-like structures, thus reducing the slope length into a series of shorter slopes.
- Serve to facilitate drainage where installed at an angle on the slope.
- Enhance conditions for colonization of native vegetation by creating surface stabilization and a microclimate conducive to plant growth.

Construction guidelines

Live materials—Cuttings must be from species, such as young willows or shrub dogwoods, that root easily and have long, straight branches.

Live material sizes and preparation

- Cuttings tied together to form live fascine bundles normally vary in length from 5 to 10 feet or longer, depending on site conditions and limitations in handling.
- The completed bundles should be 6 to 8 inches in diameter, with all of the growing tips oriented in the same direction. Stagger the cuttings in the bundles so that tops are evenly distributed throughout the length of the uniformly sized live fascine.
- Live stakes should be 2.5 feet long.

Inert materials—String used for bundling should be untreated twine.

Dead stout stakes used to secure the live fascines should be 2.5-foot long, untreated, 2 by 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length (fig 16–8). Only new, sound lumber should be used, and any stakes that shatter upon installation should be discarded.

Installation

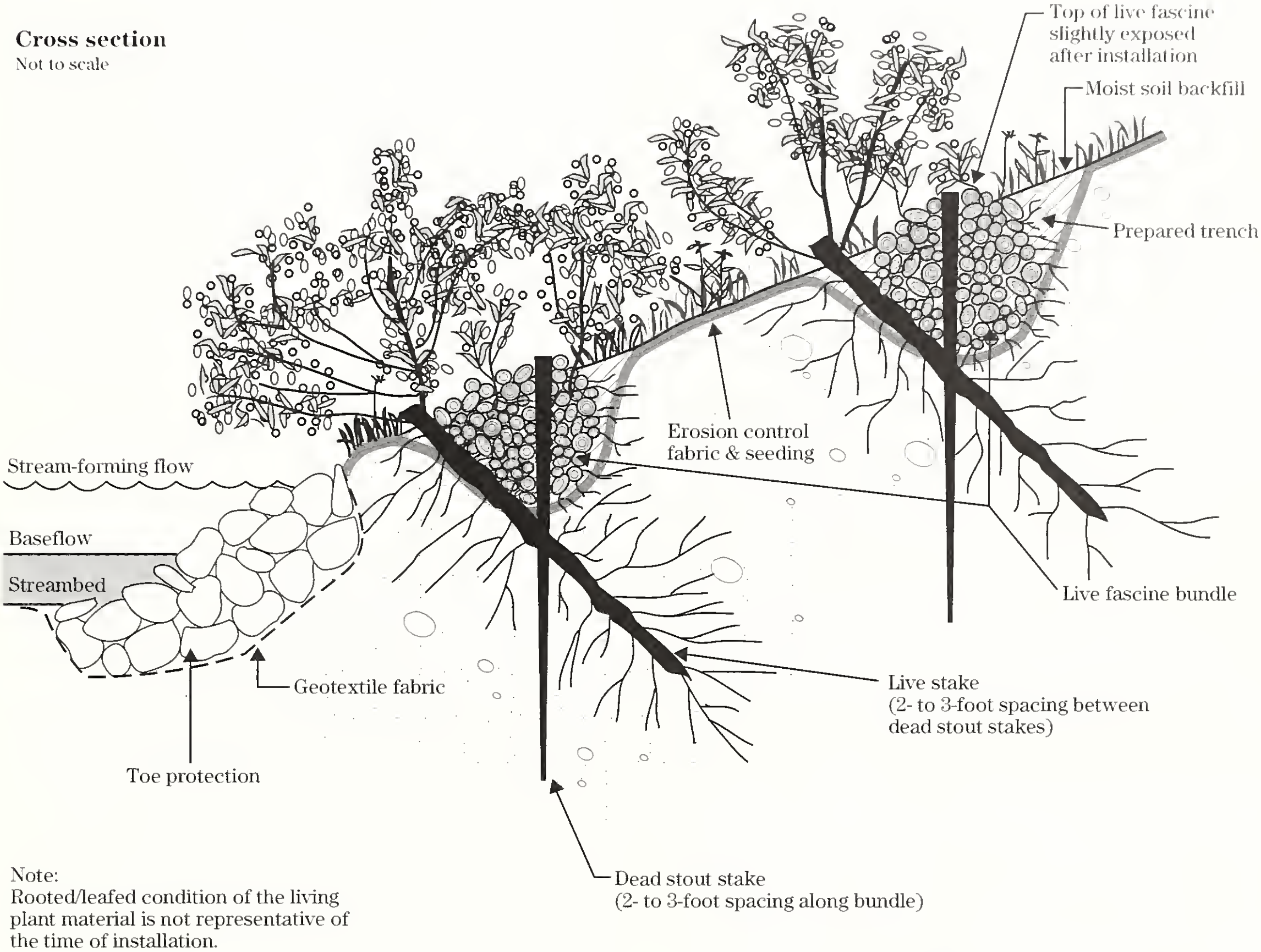
- Prepare the live fascine bundle and live stakes immediately before installation.
- Beginning at the base of the slope, dig a trench on the contour approximately 10 inches wide and deep.
- Excavate trenches up the slope at intervals specified in table 16–1. Where possible, place one or two rows over the top of the slope.
- Place long straw and annual grasses between rows.
- Install jute mesh, coconut netting, or other acceptable erosion control fabric. Secure the fabric.
- Place the live fascine into the trench (fig. 16–9a).
- Drive the dead stout stakes directly through the live fascine. Extra stakes should be used at connections or bundle overlaps. Leave the top of the dead stout stakes flush with the installed bundle.
- Live stakes are generally installed on the downslope side of the bundle. Tamp the live stakes below and against the bundle between the previously installed dead stout stakes, leaving 3 inches to protrude above the top of the ground (fig. 16–9b). Place moist soil along the sides of the bundles. The top of the live fascine should be slightly visible when the installation is completed. Figure 16–9c shows an established live fascine system 2 years after installation is completed.

Table 16–1 Live fascine spacing

Slope steepness	Soils: Erosive (feet)	Soils: Non-erosive (feet)	Soils: Fill (feet)
3:1 or flatter	3 – 5	5 – 7	3 – 5 1/
Steeper than 3:1 (up to 1:1)	3 1/	3 – 5	2/

1/ Not recommended alone.
2/ Not a recommended system.

Figure 16–7 Live fascine details



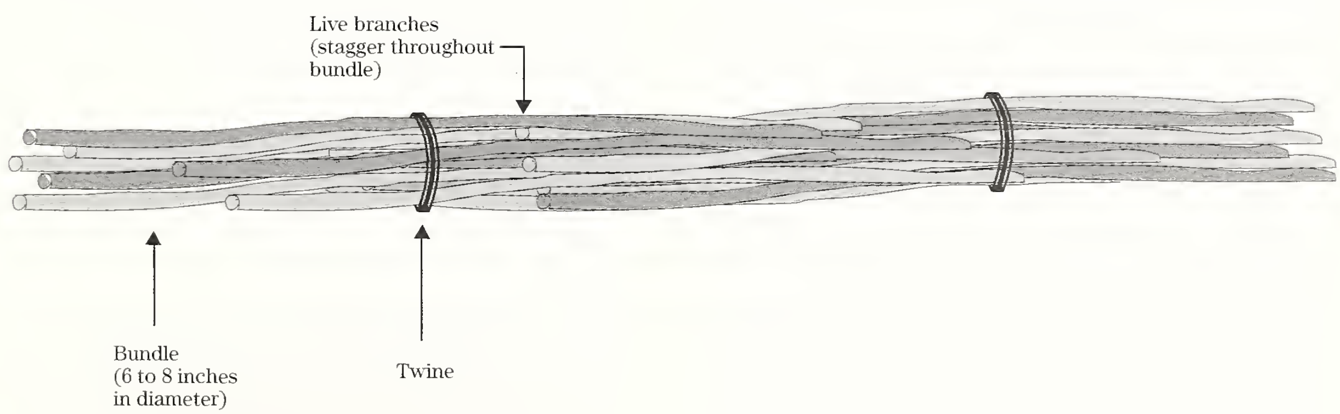


Figure 16–8 Preparation of a dead stout stake

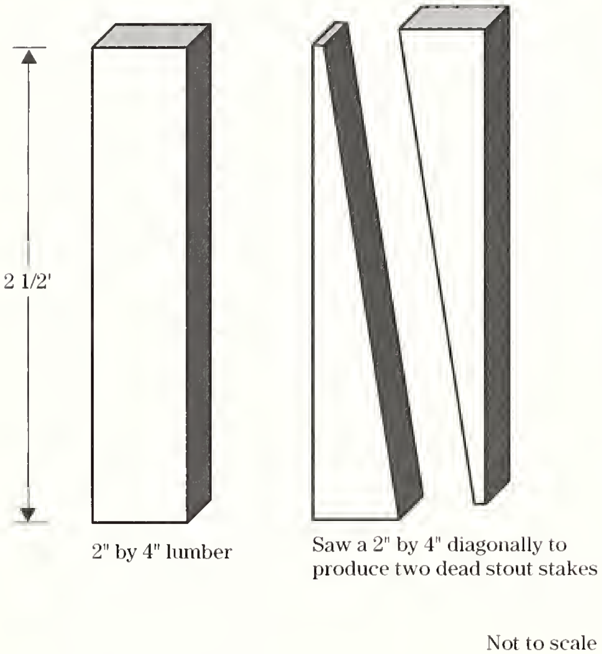


Figure 16–9a Placing live fascines (Robbin B. Sotir & Associates photo)

Figure 16–9b Installing live stakes in live fascine system (Robbin B. Sotir & Associates photo)

Figure 16–9c An established 2-year-old live fascine system (Robbin B. Sotir & Associates photo)

(iii) Branchpacking—Branchpacking consists of alternating layers of live branches and compacted backfill to repair small localized slumps and holes in streambanks (figs. 16–10, 16–11a, 16–11b, and 16–11c).

Applications and effectiveness

- Effective and inexpensive method to repair holes in streambanks that range from 2 to 4 feet in height and depth.
- Produces a filter barrier that prevents erosion and scouring from streambank or overbank flow.
- Rapidly establishes a vegetated streambank.
- Enhances conditions for colonization of native vegetation.
- Provides immediate soil reinforcement.
- Live branches serve as tensile inclusions for reinforcement once installed. As plant tops begin to grow, the branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or hole, while roots spread throughout the backfill and surrounding earth to form a unified mass.
- Typically branchpacking is not effective in slump areas greater than 4 feet deep or 4 feet wide.

Construction guidelines

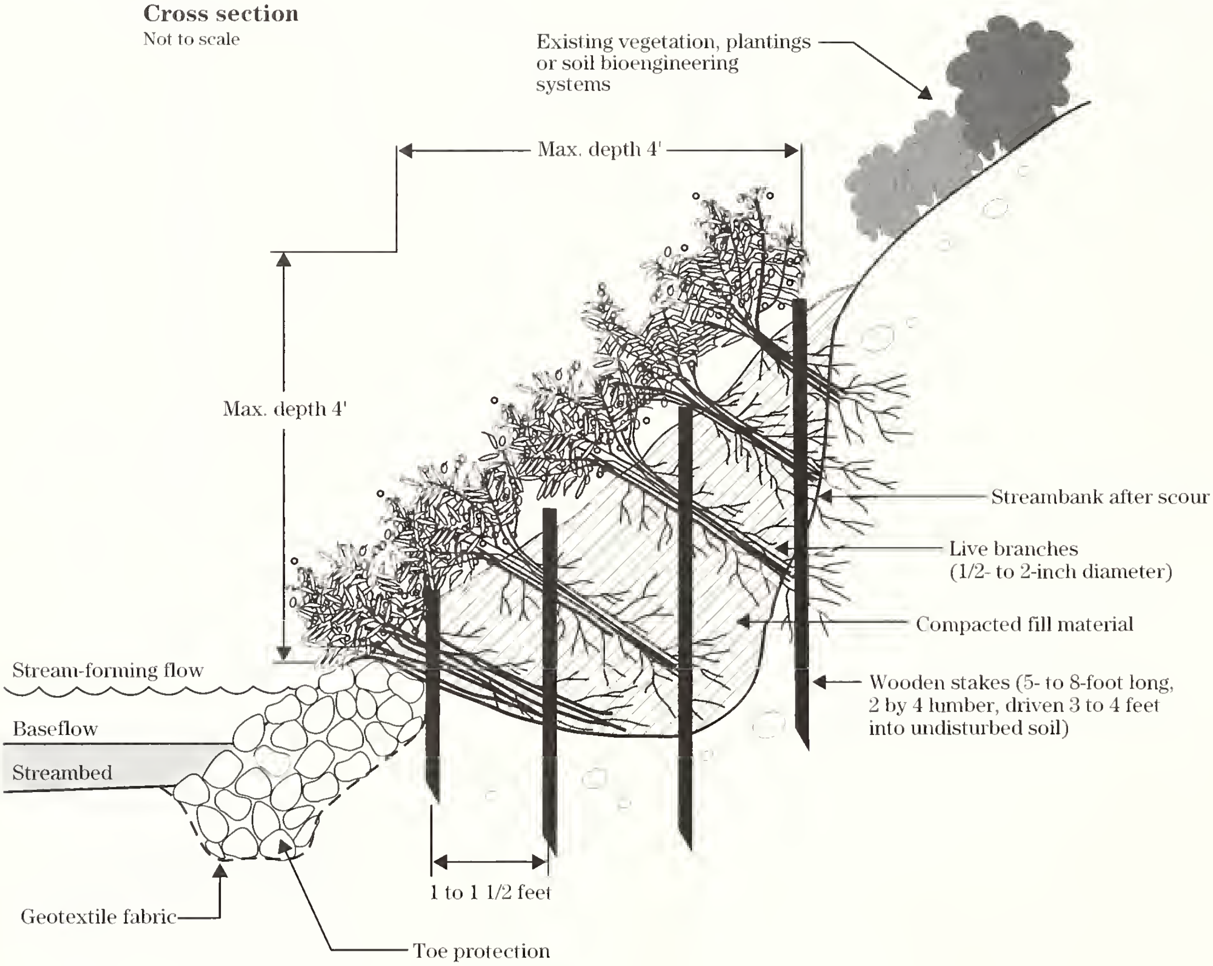
Live materials—Live branches may range from 0.5 to 2 inches in diameter. They should be long enough to touch the undisturbed soil of the back of the trench and extend slightly from the rebuilt streambank.

Inert materials—Wooden stakes should be 5 to 8 feet long and made from 3- to 4-inch diameter poles or 2 by 4 lumber, depending upon the depth of the particular slump or hole being repaired.

Installation

- Starting at the lowest point, drive the wooden stakes vertically 3 to 4 feet into the ground. Set them 1 to 1.5 feet apart.
- Place an initial layer of living branches 4 to 6 inches thick in the bottom of the hole between the vertical stakes, and perpendicular to the slope face (fig. 16–10). They should be placed in a criss-cross configuration with the growing tips generally oriented toward the slope face. Some of the basal ends of the branches should touch the undisturbed soil at the back of the hole.
- Subsequent layers of branches are installed with the basal ends lower than the growing tips of the branches.
- Each layer of branches must be followed by a layer of compacted soil to ensure soil contact with the branches.
- The final installation should conform to the existing slope. Branches should protrude only slightly from the filled installation.
- Water must be controlled or diverted if the original streambank damage was caused by water flowing over the bank. If this is not done, erosion will most likely occur on either or both sides of the new branchpacking installation.

Figure 16–10 Branchpacking details



Note:
Root/leafed condition of the living plant material is not representative of the time of installation

Figure 16–11a Live branches installed in criss-cross configuration (Robbin B. Sotir & Associates photo)

Figure 16–11b Each layer of branches is followed by a layer of compacted soil (Robbin B. Sotir & Associates photo)

Figure 16–11c A growing branchpacking system (Robbin B. Sotir & Associates photo)

(iv) Vegetated geogrids—Vegetated geogrids are similar to branchpacking except that natural or synthetic geotextile materials are wrapped around each soil lift between the layers of live branch cuttings (figs. 16–12, 16–13a, 16–13b, and 16–13c).

Applications and effectiveness

- Used above and below stream-forming flow conditions.
- Drainage areas should be relatively small (generally less than 2,000 acres) with stable streambeds.
- The system must be built during low flow conditions.
- Can be complex and expensive.
- Produce a newly constructed, well-reinforced streambank.
- Useful in restoring outside bends where erosion is a problem.
- Capture sediment, which rapidly rebuilds to further stabilize the toe of the streambank.
- Function immediately after high water to rebuild the bank.
- Produce rapid vegetative growth.
- Enhance conditions for colonization of native vegetation.
- Benefits are similar to those of branchpacking, but a vegetated geogrid can be placed on a 1:1 or steeper slope.

Construction guidelines

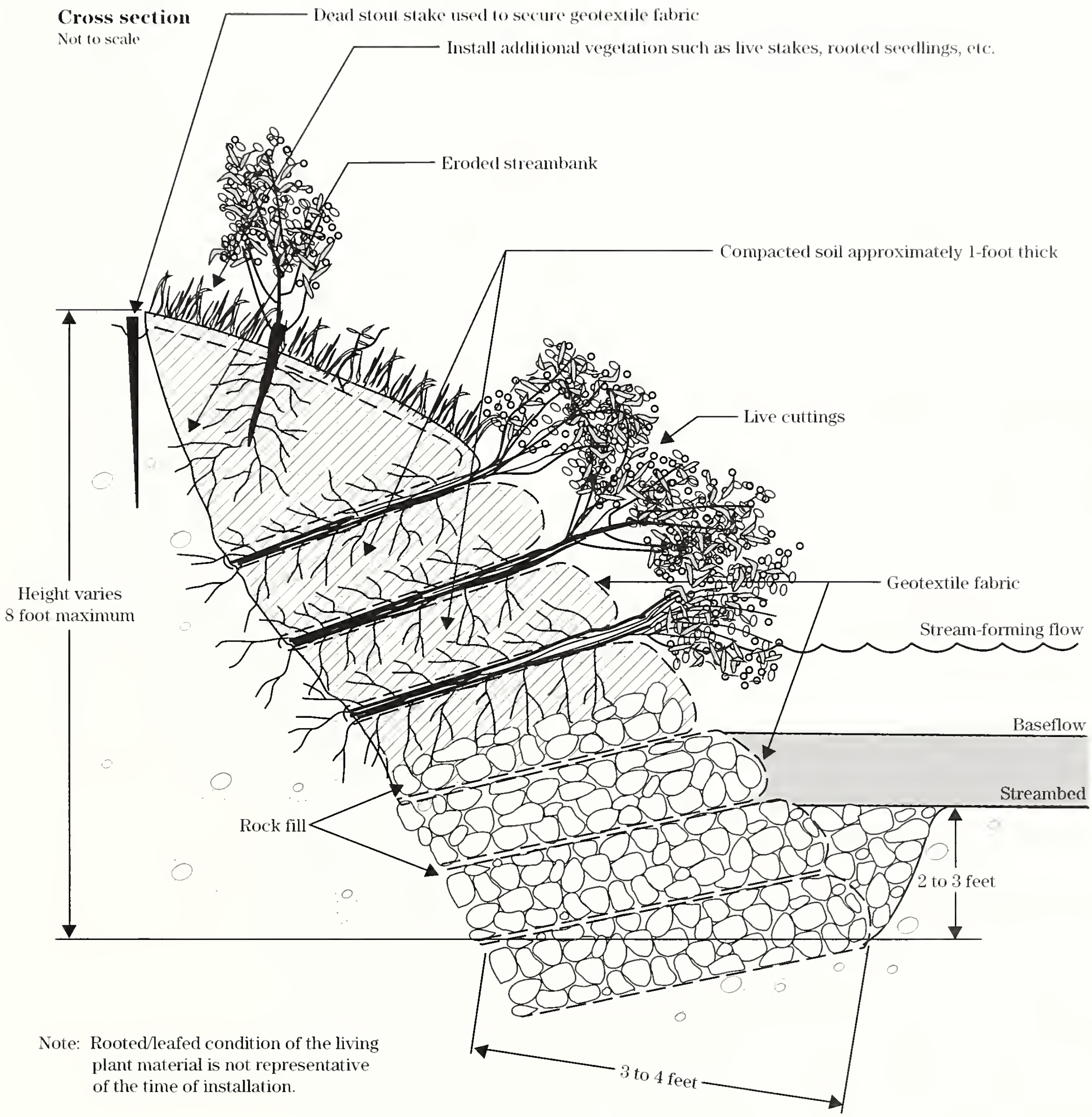
Live materials—Live branch cuttings that are brushy and root readily are required. They should be 4 to 6 feet long.

Inert materials—Natural or synthetic geotextile material is required.

Installation

- Excavate a trench that is 2 to 3 feet below streambed elevation and 3 to 4 feet wide. Place the geotextile in the trench, leaving a foot or two overhanging on the streamside face. Fill this area with rocks 2 to 3 inches in diameter.
- Beginning at the stream-forming flow level, place a 6- to 8-inch layer of live branch cuttings on top of the rock-filled geogrid with the growing tips at right angles to the streamflow. The basal ends of branch cuttings should touch the back of the excavated slope.
- Cover this layer of cuttings with geotextile leaving an overhang. Place a 12-inch layer of soil suitable for plant growth on top of the geotextile before compacting it to ensure good soil contact with the branches. Wrap the overhanging portion of the geotextile over the compacted soil to form the completed geotextile wrap.
- Continue this process of excavated trenches with alternating layers of cuttings and geotextile wraps until the bank is restored to its original height.
- This system should be limited to a maximum of 8 feet in total height, including the 2 to 3 feet below the bed. The length should not exceed 20 feet for any one unit along the stream. An engineering analysis should determine appropriate dimensions of the system.
- The final installation should match the existing slope. Branch cuttings should protrude only slightly from the geotextile wraps.

Figure 16–12 Vegetated geogrid details



Note: Rooted/leafed condition of the living plant material is not representative of the time of installation.

Figure 16–13a A vegetated geogrid during installation (Robbin B. Sotir & Associates photo)

Figure 16–13b A vegetated geogrid immediately after installation (Robbin B. Sotir & Associates photo)

Figure 16–13c Vegetated geogrid 2 years after installation (Robbin B. Sotir & Associates photo)

(v) Live cribwall—A live cribwall consists of a box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings that root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (fig. 16–14).

Applications and effectiveness

- Effective on outside bends of streams where strong currents are present.
- Appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Appropriate above and below water level where stable streambeds exist.
- Useful where space is limited and a more vertical structure is required.
- Effective in locations where an eroding bank may eventually form a split channel.
- Maintains a natural streambank appearance.
- Provides excellent habitat.
- Provides immediate protection from erosion, while established vegetation provides long-term stability.
- Supplies effective bank erosion control on fast flowing streams.
- Should be tilted back or battered if the system is built on a smooth, evenly sloped surface.
- Can be complex and expensive.

Construction guidelines

Live materials—Live branch cuttings should be 0.5 to 2.5 inches in diameter and long enough to reach the back of the wooden crib structure.

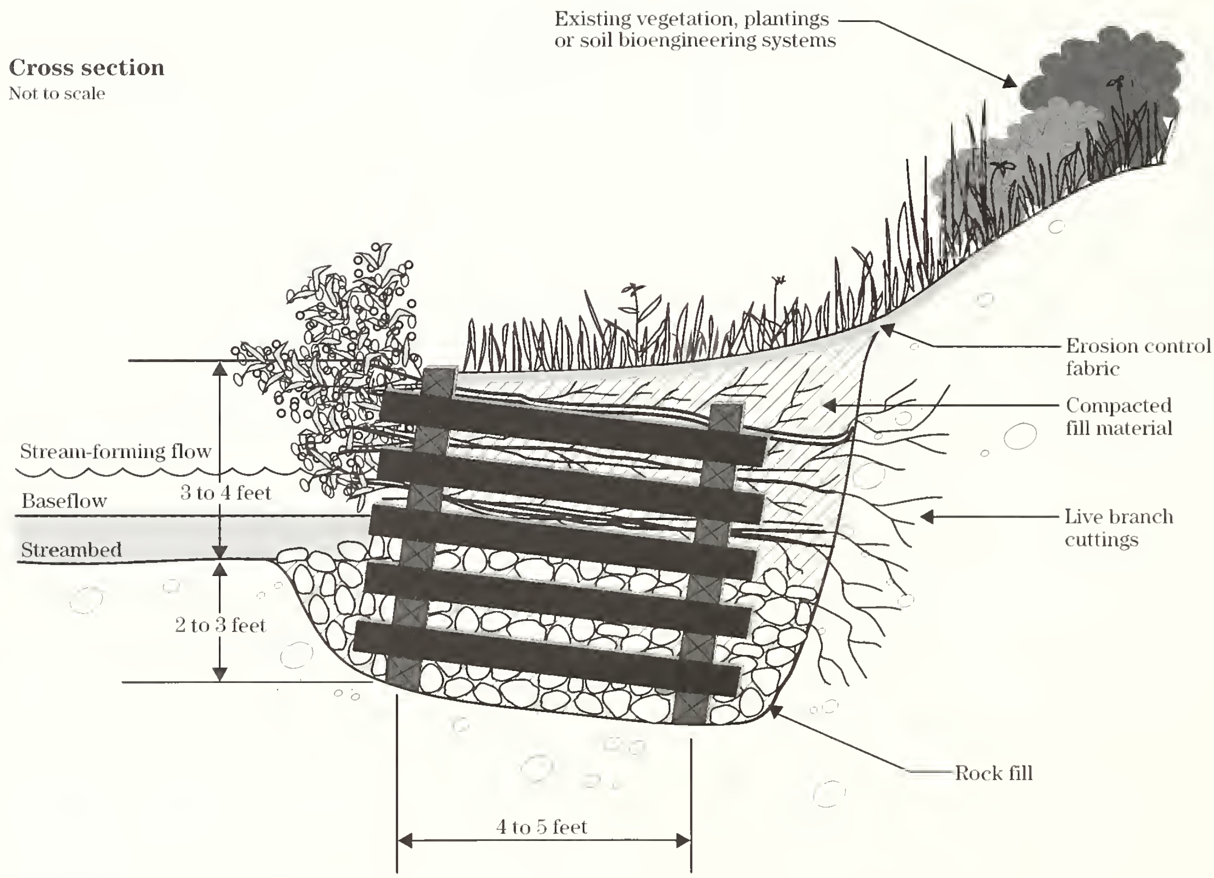
Inert materials—Logs or timbers should range from 4 to 6 inches in diameter or dimension. The lengths will vary with the size of the crib structure.

Large nails or rebar are required to secure the logs or timbers together.

Installation

- Starting at the base of the streambank to be treated, excavate 2 to 3 feet below the existing streambed until a stable foundation 5 to 6 feet wide is reached.
- Excavate the back of the stable foundation (closest to the slope) 6 to 12 inches lower than the front to add stability to the structure.
- Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4 to 5 feet apart and parallel to the slope contour.
- Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course to overhang the front and back of the previous course by 3 to 6 inches. Each course of the live cribwall is placed in the same manner and secured to the preceding course with nails or reinforcement bars.
- Place rock fill in the openings in the bottom of the crib structure until it reaches the approximate existing elevation of the streambed. In some cases it is necessary to place rocks in front of the structure for added toe support, especially in outside stream meanders.
- Place the first layer of cuttings on top of the rock material at the baseflow water level, and change the rock fill to soil fill capable of supporting plant growth at this point. Ensure that the basal ends of some of the cuttings contact undisturbed soil at the back of the cribwall.
- When the cribwall structure reaches the existing ground elevation, place live branch cuttings on the backfill perpendicular to the slope; then cover the cuttings with backfill and compact.
- Live branch cuttings should be placed at each course to the top of the cribwall structure with growing tips oriented toward the slope face. Follow each layer of branches with a layer of compacted soil. Place the basal ends of the remaining live branch cuttings so that they reach to undisturbed soil at the back of the cribwall with growing tips protruding slightly beyond the front of the cribwall (figs. 16–15a, 16–15b, and 16–15c).
- The live cribwall structure, including the section below the streambed, should not exceed a maximum height of 7 feet. An engineering analysis should determine appropriate dimensions of the system.
- The length of any single constructed unit should not exceed 20 feet.

Figure 16–14 Live cribwall details



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

Figure 16–15a Pre-construction streambank conditions

Figure 16–15b A live cribwall during installation

Figure 16–15c An established live cribwall system

(vi) Joint planting—Joint planting or vegetated riprap involves tamping live stakes into joints or open spaces in rocks that have been previously placed on a slope (fig 16–16). Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face.

Applications and effectiveness

- Useful where rock riprap is required or already in place.
- Roots improve drainage by removing soil moisture.
- Over time, joint plantings create a living root mat in the soil base upon which the rock has been placed. These root systems bind or reinforce the soil and prevent washout of fines between and below the rock.
- Provides immediate protection and is effective in reducing erosion on actively eroding banks.
- Dissipates some of the energy along the streambank.

Construction guidelines

Live material sizes—The stakes must have side branches removed and bark intact. They should be 1.5 inches or larger in diameter and sufficiently long to extend well into soil below the rock surface.

Installation

- Tamp live stakes into the openings of the rock during or after placement of riprap. The basal ends of the material must extend into the backfill or undisturbed soil behind the riprap. A steel rod or hydraulic probe may be used to prepare a hole through the riprap.
- Orient the live stakes perpendicular to the slope with growing tips protruding slightly from the finished face of the rock (figs. 16–17a, 16–17b, and 16–17c).
- Place the stakes in a random configuration.

Figure 16–16 Joint planting details

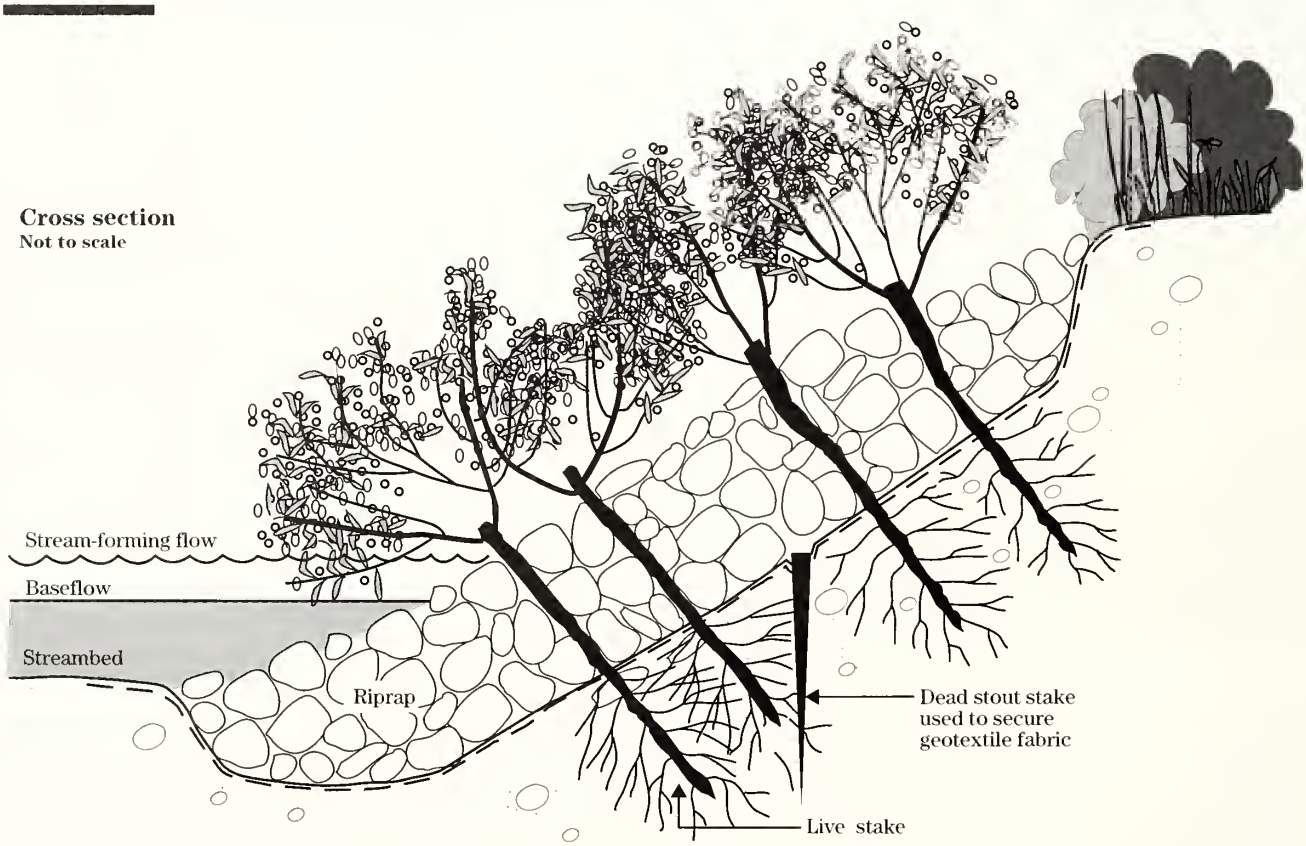


Figure 16–17a Live stake tamped into rock joints (joint planting) (Robbin B. Sotir & Associates photo)

Figure 16–17b An installed joint planting system (Robbin B. Sotir & Associates photo)

Figure 16–17c An established joint planting system (Robbin B. Sotir & Associates photo)

(vii) Brushmattress—A brushmattress is a combination of live stakes, live fascines, and branch cuttings installed to cover and stabilize streambanks (figs. 16–18, 16–19a through 16–19d). Application typically starts above stream-forming flow conditions and moves up the slope.

Applications and effectiveness

- Forms an immediate, protective cover over the streambank.
- Useful on steep, fast-flowing streams.
- Captures sediment during flood conditions.
- Rapidly restores riparian vegetation and streamside habitat.
- Enhances conditions for colonization of native vegetation.

Construction guidelines

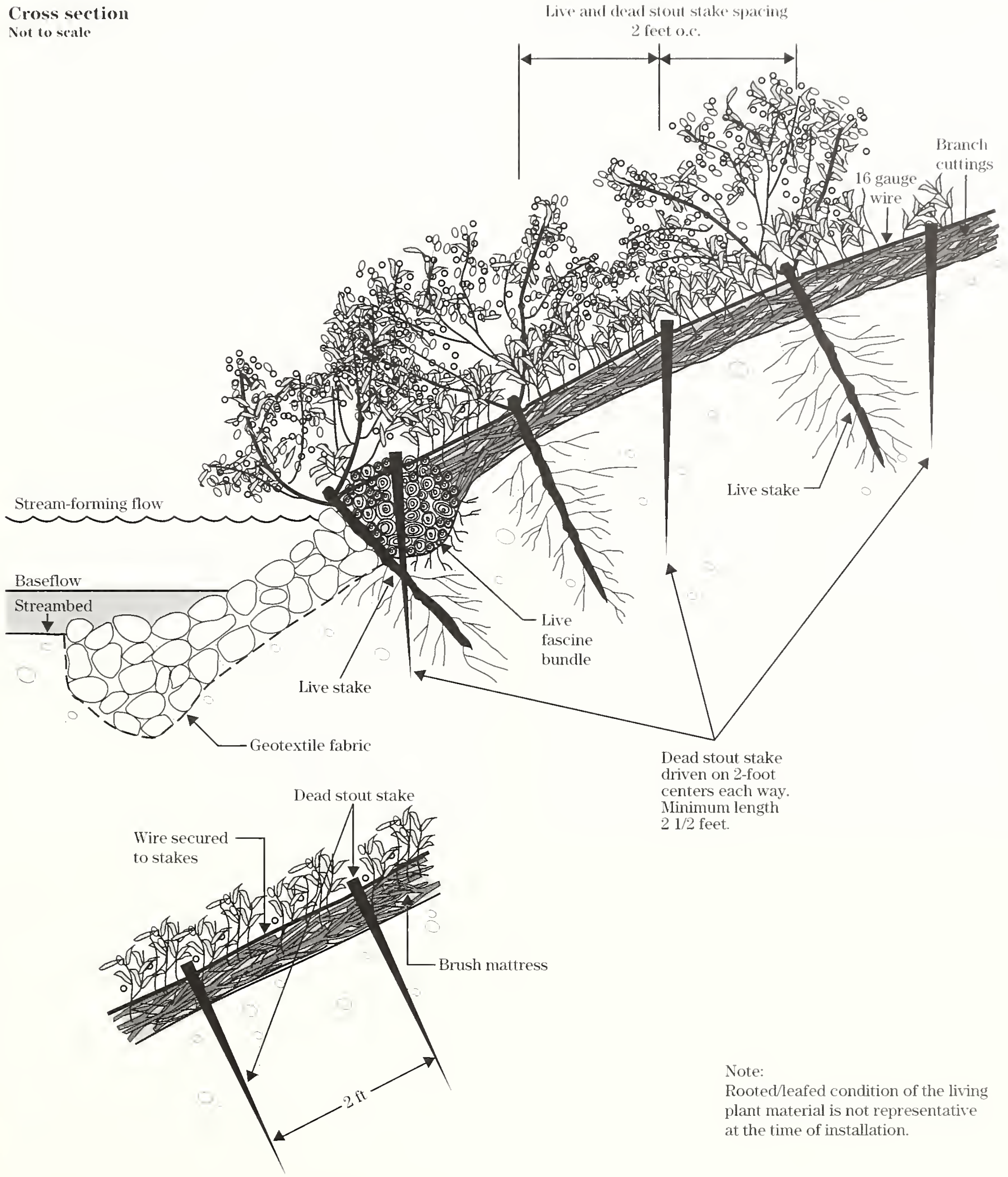
Live materials—Branches 6 to 9 feet long and approximately 1 inch in diameter are required. They must be flexible to enable installations that conform to variations in the slope face. Live stakes and live fascines are previously described in this chapter.

Inert materials—Untreated twine for bundling the live fascines and number 16 smooth wire are needed to tie down the branch mattress. Dead stout stakes to secure the live fascines and brushmattress in place.

Installation

- Grade the unstable area of the streambank uniformly to a maximum steepness of 3:1.
- Prepare live stakes and live fascine bundles immediately before installation, as previously described in this chapter.
- Beginning at the base of slope, near the stream-forming flow stage, excavate a trench on the contour large enough to accommodate a live fascine and the basal ends of the branches.
- Install an even mix of live and dead stout stakes at 1-foot depth over the face of the graded area using 2-foot square spacing.
- Place branches in a layer 1 to 2 branches thick vertically on the prepared slope with basal ends located in the previously excavated trench.
- Stretch No. 16 smooth wire diagonally from one dead stout stake to another by tightly wrapping wire around each stake no closer than 6 inches from its top.
- Tamp and drive the live and dead stout stakes into the ground until branches are tightly secured to the slope.
- Place live fascines in the prepared trench over the basal ends of the branches.
- Drive dead stout stakes directly through into soil below the live fascine every 2 feet along its length.
- Fill voids between brushmattress and live fascine cuttings with thin layers of soil to promote rooting, but leave the top surface of the brushmattress and live fascine installation slightly exposed.

Figure 16–18 Brushmattress details



Note:
Rooted/leafed condition of the living plant material is not representative at the time of installation.

Figure 16–19a Brushmattress during installation (Robbin B. Sotir & Associates photo)

Figure 16–19b An installed brushmattress system (Robbin B. Sotir & Associates photo)

Figure 16–19c Brushmattress system 6 months after installation (Robbin B. Sotir & Associates photo)

Figure 16–19d Brushmattress system 2 years after installation (Robbin B. Sotir & Associates photo)

(4) Structural measures

Structural measures include tree revetments; log, rootwad and boulder revetments; dormant post plantings; piling revetments with wire or geotextile fencing; piling revetments with slotted fencing; jacks or jack fields; rock riprap; stream jetties; stream barbs; and gabions.

(i) Tree revetment—A tree revetment is constructed from whole trees (except rootwads) that are usually cabled together and anchored by earth anchors, which are buried in the bank (figs. 16–20, 16–21a, and 16–21b).

Applications and effectiveness

- Uses inexpensive, readily available materials to form semi-permanent protection.
- Captures sediment and enhances conditions for colonization of native species.
- Has self-repairing abilities following damage after flood events if used in combination with soil bioengineering techniques.
- Not appropriate near bridges or other structures where there is high potential for downstream damage if the revetment dislodges during flood events.
- Has a limited life and may need to be replaced periodically, depending on the climate and durability of tree species used.
- May be damaged in streams where heavy ice flows occur.
- May require periodic maintenance to replace damaged or deteriorating trees.

Construction guidelines

- Lay the cabled trees along the bank with the basal ends oriented upstream.
- Overlap the trees to ensure continuous protection to the bank.
- Attach the trunks by cables to anchors set in the bank. Pilings can be used in lieu of earth anchors in the bank if they can be driven well below the point of maximum bed scour. The required cable size and anchorage design are dependent upon many variables and should be custom designed to fit specific site conditions.
- Use trees that have a trunk diameter of 12 inches or larger. The best type are those that have a brushy top and durable wood, such as douglas fir, oak, hard maple, or beech.
- Use vegetative plantings or soil bioengineering systems within and above structures to restore stability and establish a vegetative community. Tree species that will withstand inundation should be staked in openings in the revetment below stream-forming flow stage.

Figure 16–20 Tree revetment details

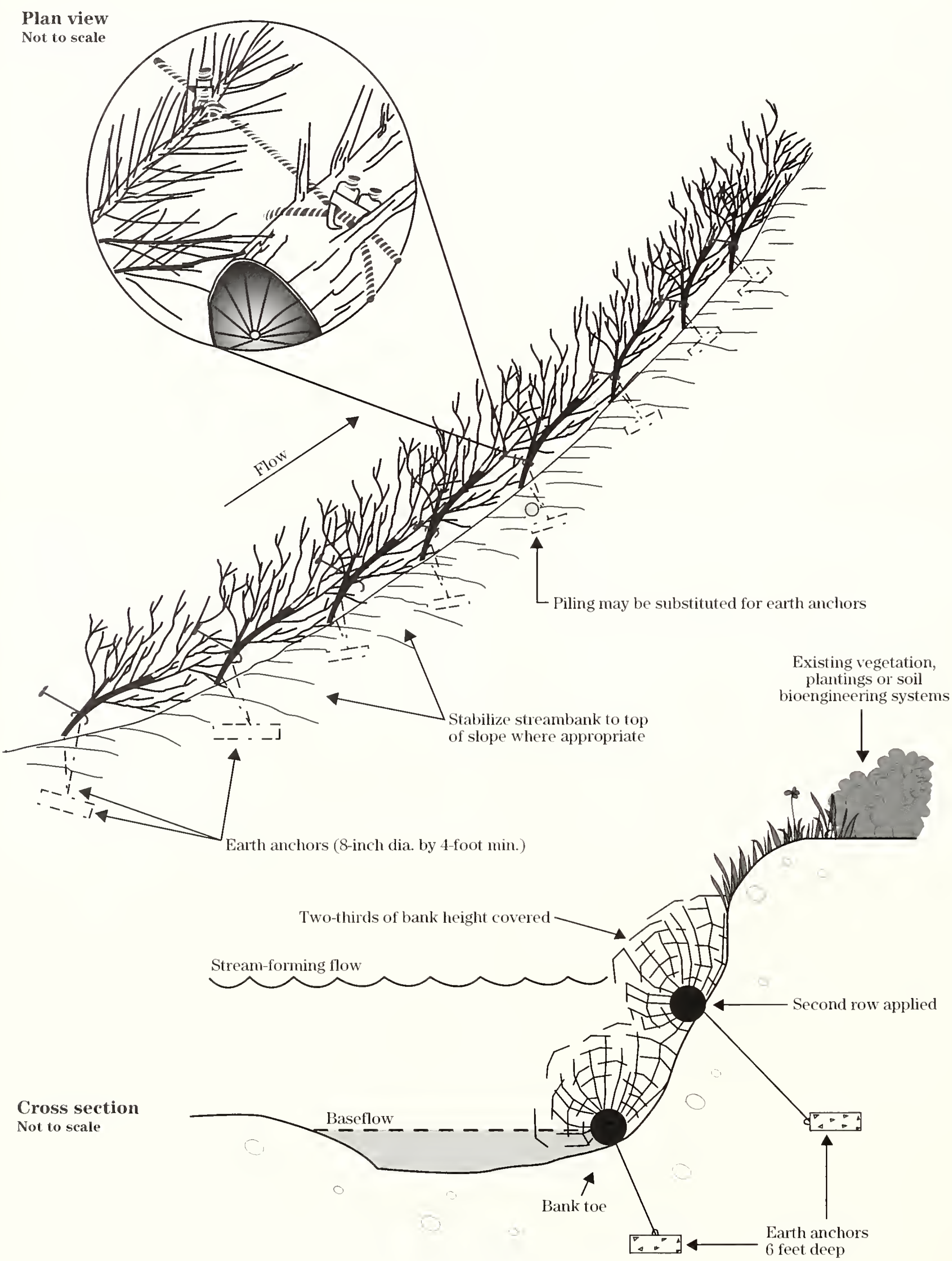


Figure 16–21a Tree revetment system with dormant posts

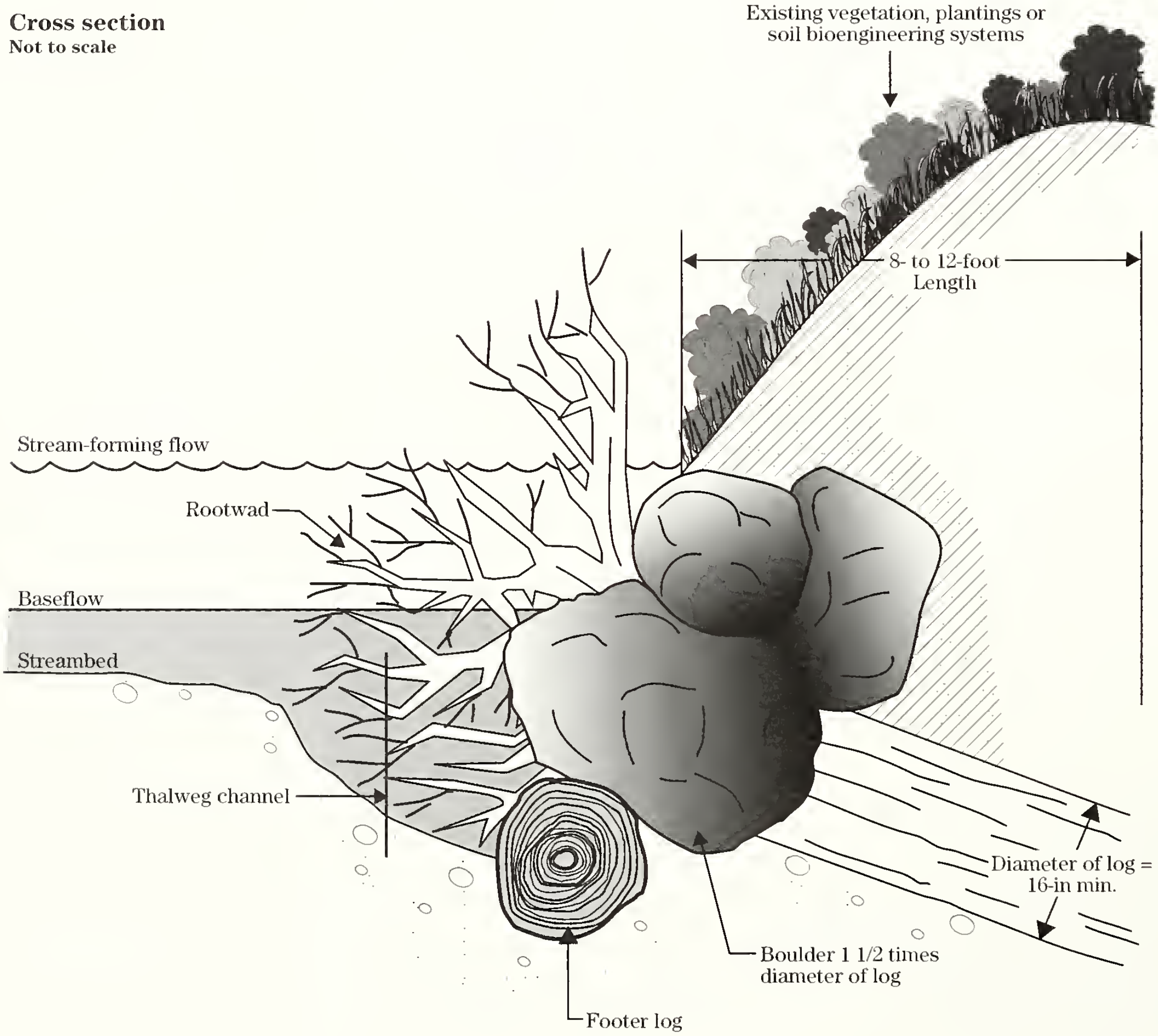
Figure 16–21b Tree revetment system with dormant posts, 2 years after installation

(ii) Log, rootwad and boulder revetments—These revetments are systems composed of logs, rootwads, and boulders selectively placed in and on streambanks (figs. 16–22 and 16–23). These revetments can provide excellent overhead cover, resting areas, shelters for insects and other fish food organisms, substrate for aquatic organisms, and increased stream velocity that results in sediment flushing and deeper scour pools. Several of these combinations are described in Flosi and Reynolds (1991), Rosgen (1992) and Berger (1991).

Applications and effectiveness

- Used for stabilization and to create instream structures for improved fish rearing and spawning habitat
- Effective on meandering streams with out-of-bank flow conditions.
- Will tolerate high boundary shear stress if logs and rootwads are well anchored.
- Suited to streams where fish habitat deficiencies exist.
- Should be used in combination with soil bioengineering systems or vegetative plantings to stabi-

Figure 16–22 Log, rootwad, and boulder revetment details (adapted from Rosgen 1993—Applied fluvial geomorphology short course)



lize the upper bank and ensure a regenerative source of streambank vegetation.

- Enhance diversity of riparian corridor when used in combination with soil bioengineering systems.
- Have limited life depending on climate and tree species used. Some species, such as cottonwood or willow, often sprout and accelerate natural colonization. Revetments may need eventual replacement if natural colonization does not take place or soil bioengineering methods are not used in combination.

Construction guidelines

Numerous individual organic revetments exist and many are detailed in the U.S. Forest Service publication, *Stream Habitat Improvement Handbook*. Chapter 16 only presents construction guidelines for a combination log, rootwad, and boulder revetment.

- Use logs over 16 inches in diameter that are crooked and have an irregular surface.
- Use rootwads with numerous root protrusions and 8- to 12-foot long boles.
- Boulders should be as large as possible, but at a minimum one and one-half the log diameter. They should have an irregular surface.
- Install a footer log at the toe of the eroding bank by excavating trenches or driving them into the bank to stabilize the slope and provide a stable foundation for the rootwad.
- Place the footer log to the expected scour depth at a slight angle away from the direction of the stream flow.
- Use boulders to anchor the footer log against flotation. If boulders are not available, logs can be pinned into gravel and rubble substrate with 3/4-inch rebar 54 inches or longer. Anchor rebar to provide maximum pull out resistance. Cable and anchors may also be used in combination with boulders and rebar.
- Drive or trench and place rootwads into the streambank so that the tree's primary brace roots are flush with the streambank. Place the rootwads at a slight angle toward the direction of the streamflow.
- Backfill and combine vegetative plantings or soil bioengineering systems behind and above rootwad. They can include live stakes and dormant post plantings in the openings of the revetment below stream-forming flow stage, live stakes, bare root, or other upland methods at the top of the bank.

Figure 16–23 Rootwad, boulder, and willow transplant revetment system, Weminuche River, CO (Rosgen, Wildland hydrology)

(iii) Dormant post plantings—Dormant post plantings form a permeable revetment that is constructed from rootable vegetative material placed along streambanks in a square or triangular pattern (figs. 16–24, 16–25a, 16–25b, 16–25c).

Applications and effectiveness

- Well suited to smaller, non-gravely streams where ice damage is not a problem.
- Quickly re-establish riparian vegetation.
- Reduce stream velocities and causes sediment deposition in the treated area.
- Enhance conditions for colonization of native species.
- Are self-repairing. For example, posts damaged by beaver often develop multiple stems.
- Can be used in combination with soil bioengineering systems.
- Can be installed by a variety of methods including water jetting or mechanized stingers to form planting holes or driving the posts directly with machine mounted rams.
- Unsuccessfully rooted posts at spacings of about 4 feet can provide some benefits by deflecting higher streamflows and trapping sediment.

Construction guidelines

- Select a plant species appropriate to the site conditions. Willows and poplars have demonstrated high success rates.
- Cut live posts approximately 7 to 9 feet long and 3 to 5 inches in diameter. Taper the basal end of the post for easier insertion into the ground.
- Install posts into the eroding bank at or just above the normal waterline. Make sure posts are installed pointing up.
- Insert one-half to two-thirds of the length of post below the ground line. At least the bottom 12 inches of the post should be set into a saturated soil layer.
- Avoid excessive damage to the bark of the posts.
- Place two or more rows of posts spaced 2 to 4 feet apart using square or triangular spacing.
- Supplement the installation with appropriate soil bioengineering systems or, where appropriate, rooted plants.

Figure 16-24 Dormant post details

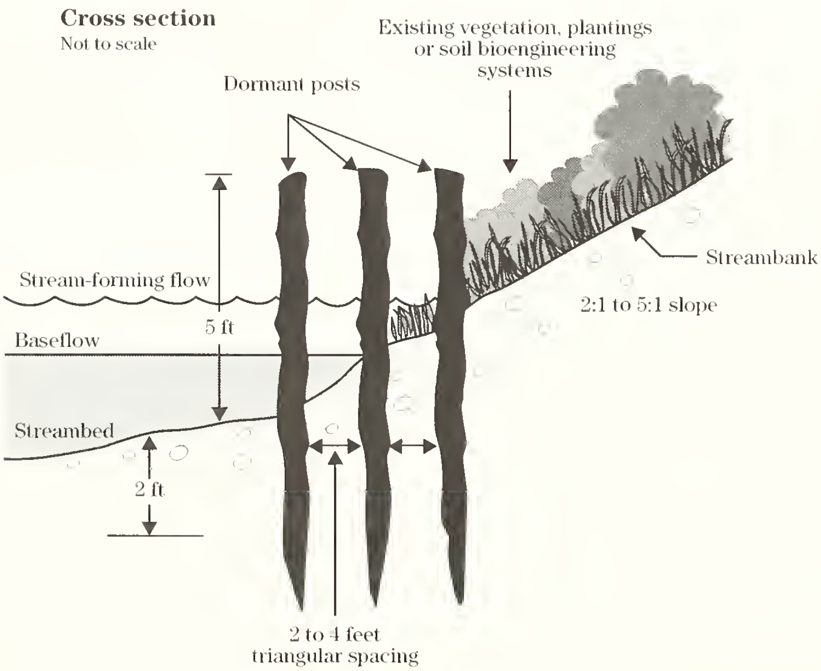


Figure 16–25a Pre-construction streambank conditions (Don Roseboom photo)

Figure 16–25b Installing dormant posts (Don Roseboom photo)

Figure 16–25c Established dormant post system (Don Roseboom photo)

***(iv) Piling revetment with wire or geotextile fencing*—**Piling revetment is a continuous single or double row of pilings with a facing of woven wire or geogrid material (fig. 16–26). The space between double rows of pilings is filled with rock and brush.

Applications and effectiveness

- Particularly suited to streams where water next to the bank is more than 3 feet deep.
- Application is limited to a flow depth (and height of piling) of 6 feet.
- More economical than riprap construction in deep water because it eliminates the need to build a stable foundation under water for holding the riprap in place.
- Is easily damaged by ice flows or heavy flood debris and should not be used where these conditions occur.
- Do not use where the stream has fish or an abundance of riparian wildlife.
- Do not use without careful analysis of its long-term effects upon aesthetics, changes in flows where large amounts of debris will be collected, habitat damage caused by driving or installing pilings with water jets, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

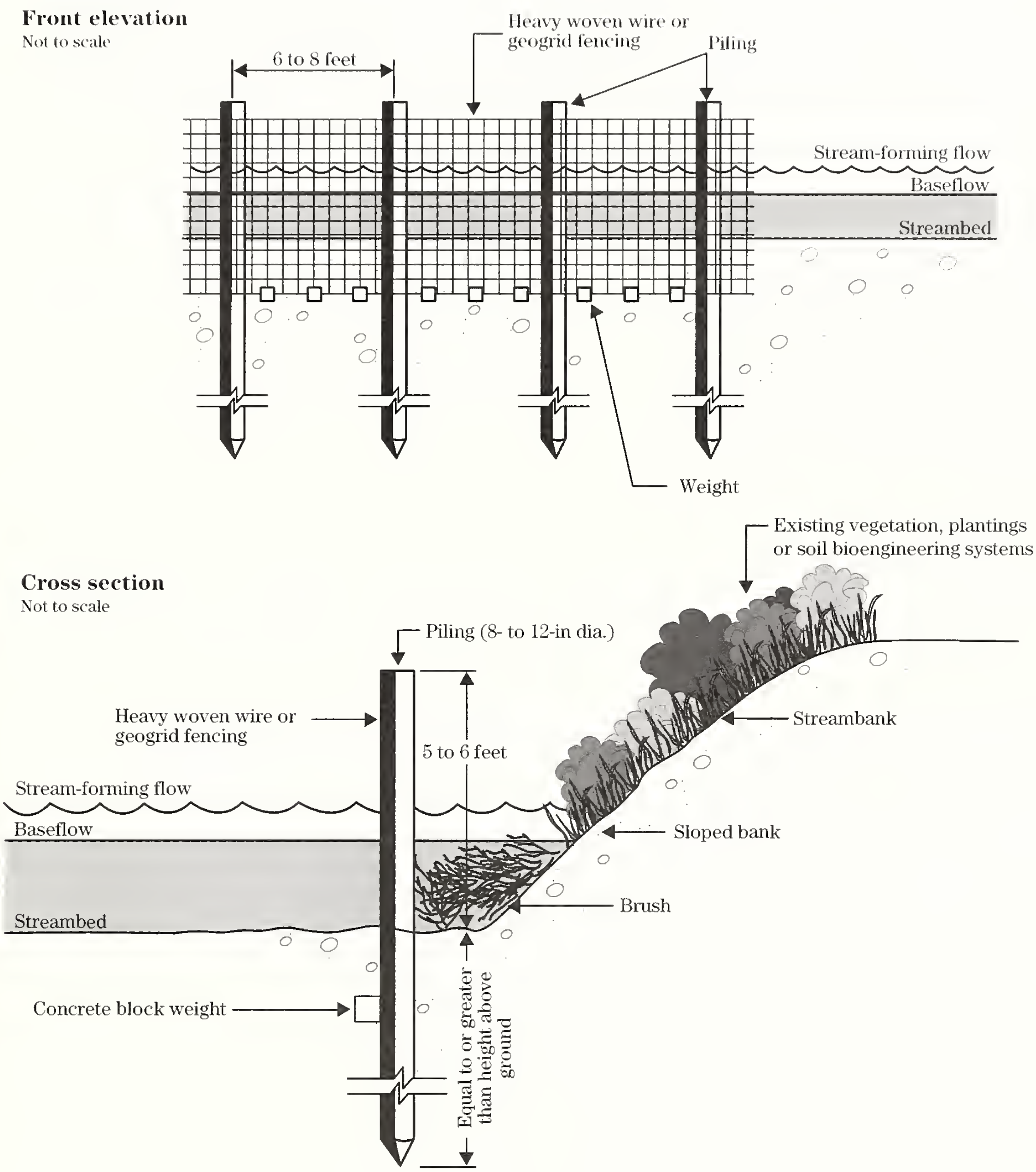
Construction guidelines

Inert materials—Used material, such as timbers, logs, railroad rails, or pipe, may be used for pilings. Logs should have a diameter sufficiently large to permit driving to the required depth. Avoid material that may produce toxicity effects in aquatic ecosystems.

Installation

- Beginning at the base of the streambank, near stream-forming flow stage, drive pilings 6 to 8 feet apart to a depth approximately half their length and below the point of maximum scour. If the streambed is firm and not subject to appreciable scour, the piling should be driven to refusal or to a depth of at least half the length of the piling.
- Additional rows of pilings may be installed at higher elevations on the streambank if required to protect the bank and if using vegetation or other methods is not practical.
- Fasten a heavy gauge of woven wire or geotextile material to the stream side of the pilings to form a fence. The purpose of this material is to collect debris while serving as a permeable wall to reduce velocities on the streambank.
- Double row piling revetment is typically constructed with 5 feet between rows. Fill the row space with rock and brush.
- If the streambed is subject to scour, extend the woven wire or geotextile material horizontally toward the center of the streambed for a distance at least equal to the anticipated depth of scour. Attach concrete blocks or other suitable weights at regular intervals to cause the fence to settle in a vertical position along the face of the pilings after scouring occurs.
- Place brush behind the piling to increase the system's effectiveness. Where piling revetments extend for several hundred feet in length, install permeable groins or tiebacks of brush and rock at right angles to the revetment at 50 foot intervals. This reduces currents developing between the streambank and the revetment.

Figure 16–26 Piling revetment details

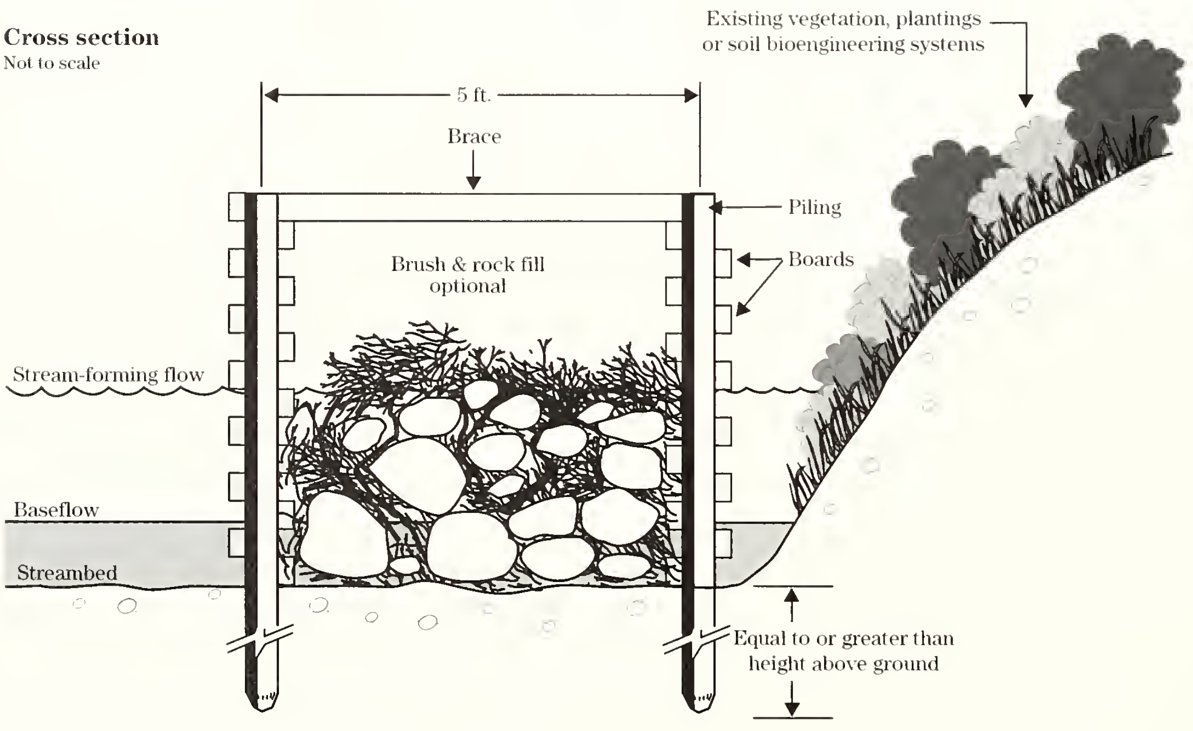


(v) Piling revetment with slotted board fencing—This type of revetment consists of slotted board fencing made of wood pilings and horizontal wood timbers (figs. 16–27 and 16–28). Variations include different fence heights, double rows of slotted fence, and use of woven wire in place of timber boards. The size and spacing of pilings, cross members, and vertical fence boards depend on height of fence, stream velocity, and sediment load.

Applications and effectiveness

- Most variations of slotted fencing include some bracing or tieback into the streambank to increase strength, reduce velocity against the streambank, and to trap sediment.
- Should not be constructed higher than 3 feet without an engineering analysis to determine sizes of the structural members.
- May be vulnerable to damage by ice or heavy flood debris; should not be used where these conditions occur.
- Usually complex and expensive.
- Most effective on streams that have a heavy sediment load of sand and silt.
- Can withstand a relatively high velocity attack force and, therefore, can be installed in sharper curves than jacks or other systems.
- Useful in deeper stream channels with large flow depths.
- Low slotted board fences, which do not control the entire flood flow, can be very effective for streambank toe protection where the toe is the weak part of the streambank.
- May not be appropriate where unusually hard materials are encountered in the channel bottom.

Figure 16–27 Slotted board fence details (double fence option)



- Should not be used without careful consideration of its long-term effects upon aesthetics, changes in flows where large amounts of debris are collected, habitat damage caused by driving or installing pilings with water jets, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Construction guidelines
Inert materials—Slotted fencing is constructed of wood boards, wood pilings, and woven wire. Avoid materials that may produce toxicity effects in aquatic ecosystems.

Installation
- See *(iv) Piling revetment with wire or geotextile fencing* for general construction guidelines.
- Drive the timber piling to a depth below the channel bottom that is equal to the height of the slotted fence above the expected scour line when stream soils have a standard penetration resistance of 10 or more blows per foot. Increase the piling depth when penetration resistance is less than 10 blows per foot.
- Take great care during layout to tie in the upstream end adequately to prevent flanking and unraveling.

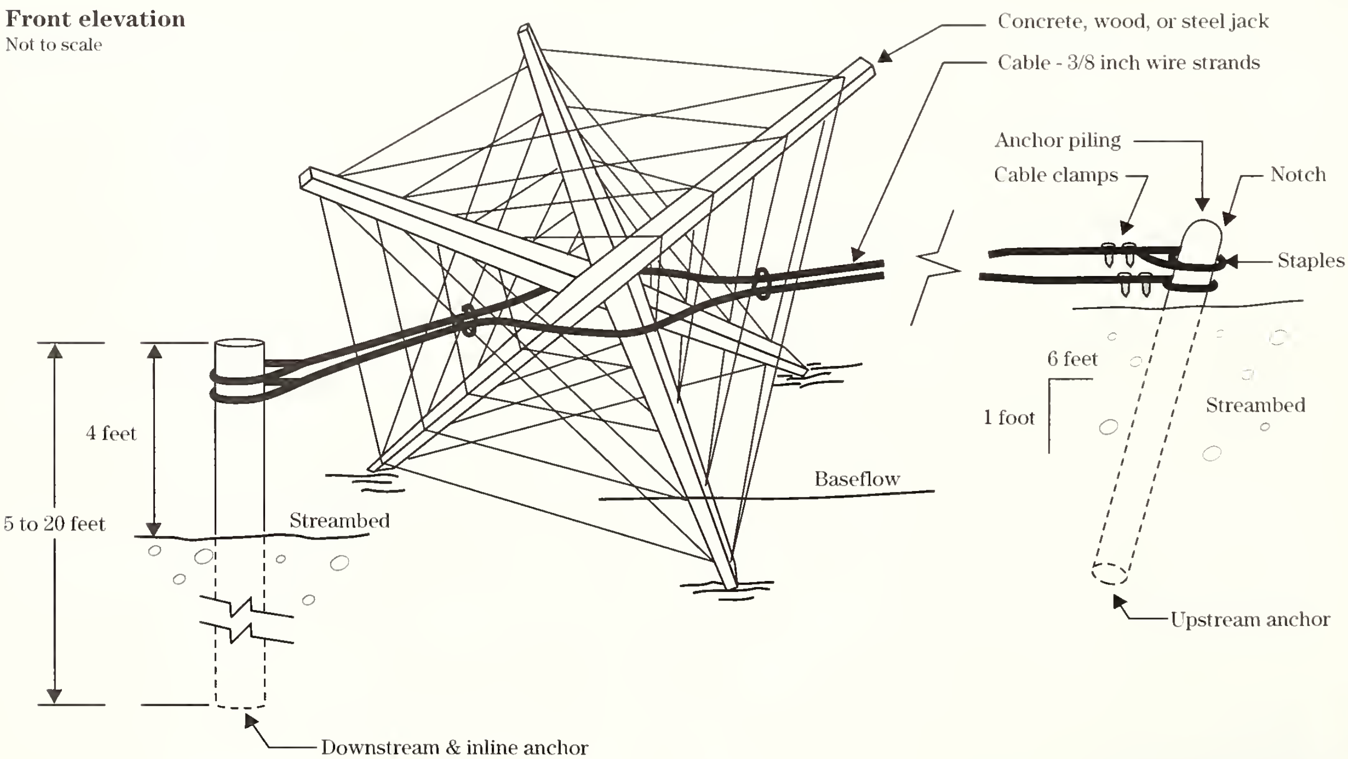
Figure 16–28 Slotted board fence system

(vi) Jacks or jack fields—Jacks are individual structures made of wood, concrete, or steel. The jacks are placed in rows parallel to the eroding streambank and function by trapping debris and sediment. They are often constructed in groups called jack fields (figs. 16–29, 16–30, and 16–31).

Applications and effectiveness

- May be an effective means of controlling bank erosion on sinuous streams carrying heavy bedloads of sand and silt during flood flows. This condition is generally indicated by the presence of extensive sandbar formations on the bed at low flow.
- Are complex systems requiring proper design and installation for effective results.
- Collect coarse and fine sediment, when functioning properly, and naturally revegetate as the systems, including cable, become embedded in the streambank.
- Do not use on high velocity, debris-laden streams.
- Somewhat flexible because of their physical configuration and installation techniques that allow them to adjust to slight changes in the channel grade.
- Most effective on long, radius curves.
- Not an effective alternative for redirecting flow away from the streambank.
- Do not use without careful analysis of its long-term effects upon aesthetics, changes in flows where large amounts of debris are collected, fish habitat damage, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Figure 16–29 Concrete jack details

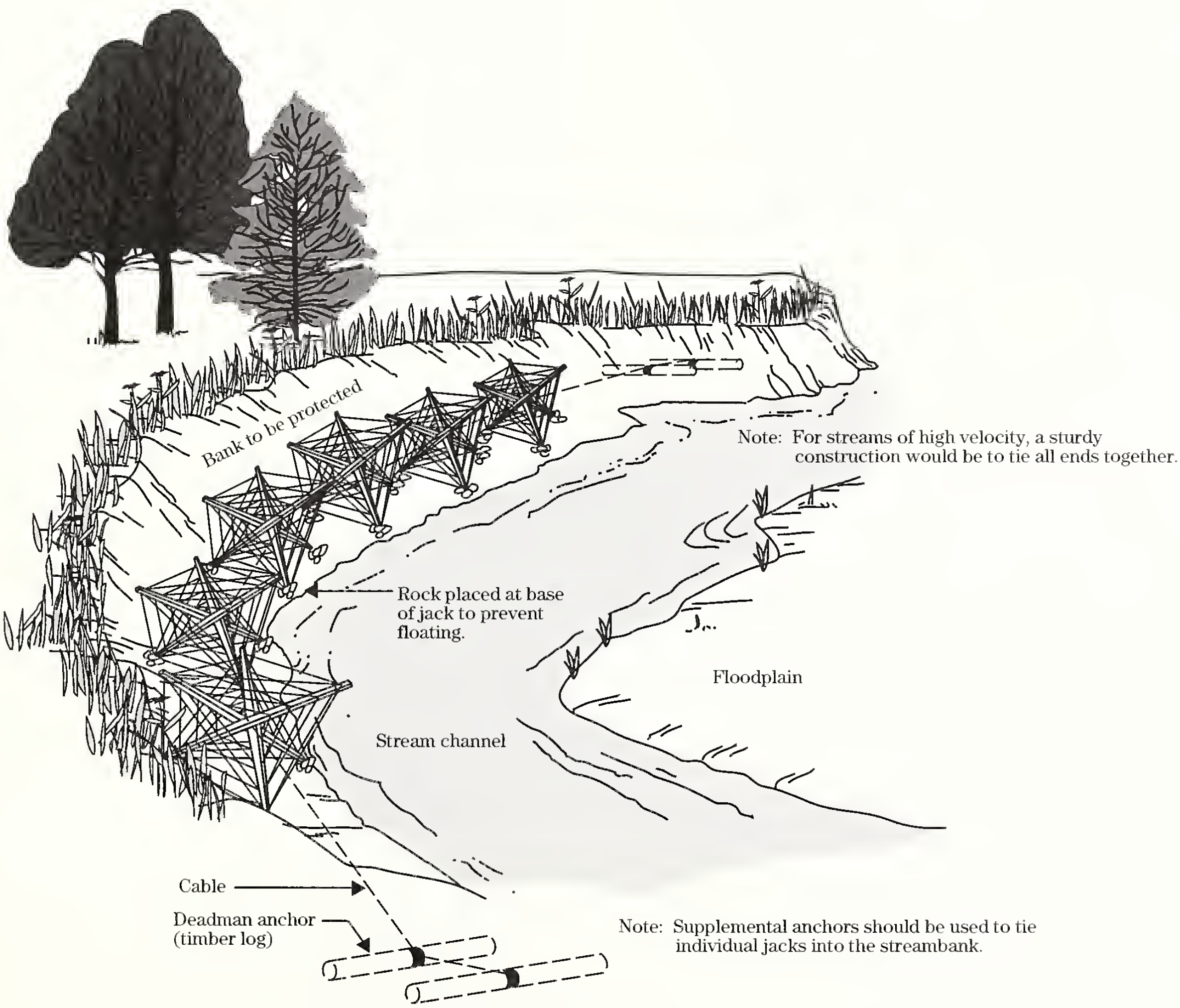


Construction guidelines

Inert materials—Jacks may be constructed of wood, steel, or concrete. Wooden jacks are constructed from three poles 10 to 16 feet long. They are crossed and wired together at the ends and midpoints with No. 9 galvanized wire. Cables used to anchor the wood jack systems should be 3/8-inch diameter or larger with a minimum breaking strength of 15,400 pounds. Wooden jack systems dimensioned in this chapter are limited to shallow flow depths of 12 feet or less.

Steel jacks are used in a manner similar to that of wood jacks; however, leg assemblies, cable size, anchor blocks, and anchor placement details vary. Concrete beams may be substituted for steel, but engineering design is required to determine different attachment methods, anchoring systems, and assembly configurations.

Figure 16–30 Wooden jack field



Installation

- Jack rows can be placed on a shelf 14 feet wide for one line and on two shelves, each 14 feet wide, for a double jack row. Grade the shelf to slope from 1 foot above the streambed at the side nearest the stream to 3 feet above the streambed at the side nearest the slope. This encourages a dry surface for construction and provides some additional elevation for protection from greater depths of flow. Alternatively, jacks can be constructed on the streambed or on the top of the bank and moved into place.
- Space jacks closely together with a maximum of one jack dimension between them to provide an almost continuous line of revetment.
- Anchor the jacks in place by a cable strung through and tied to the center of the jacks with cable clamps. The cable should be tied to a buried anchor or pilings, thereby securing all the jacks as a unit. Wooden jacks are weighted by rocks, which should be wired onto the jack poles. The first two pilings at the upstream end of the jack line should be driven no more than 12 feet apart to reduce the effect of increased water force from trash buildup.
- Bury anchors or drive anchor pilings to the design depth determined by an engineer. Depths may vary from 5 to 20 feet and must be specified based on individual site characteristics.
- On long curves, anchor jack rows at intermediate points along the curve to isolate damages to the jack row. Two 3/8-inch diameter wire cables tied to timber or steel pilings provide adequate anchors. Place anchors up the streambank rather than in the streambed.
- Consider pilings if streambed anchors are required. Space pilings 75 to 125 feet apart along the jack row, with closer spacing on shorter curves.
- Attach an anchored 3/8-inch diameter wire cable to one leg of each jack to prevent rotation and improve stability.
- Place jack rows perpendicular to the bank at regular intervals where jack rows are not close to existing banks. This prevents local scour. Extend bank protection far enough to prevent flanking action. Ensure the jack row is anchored to a hardpoint at the upstream end.
- Supplement the jack string or field with vegetative plantings. Dormant posts offer a compatible component in the system.

Figure 16–31 Concrete jack system several years after installation

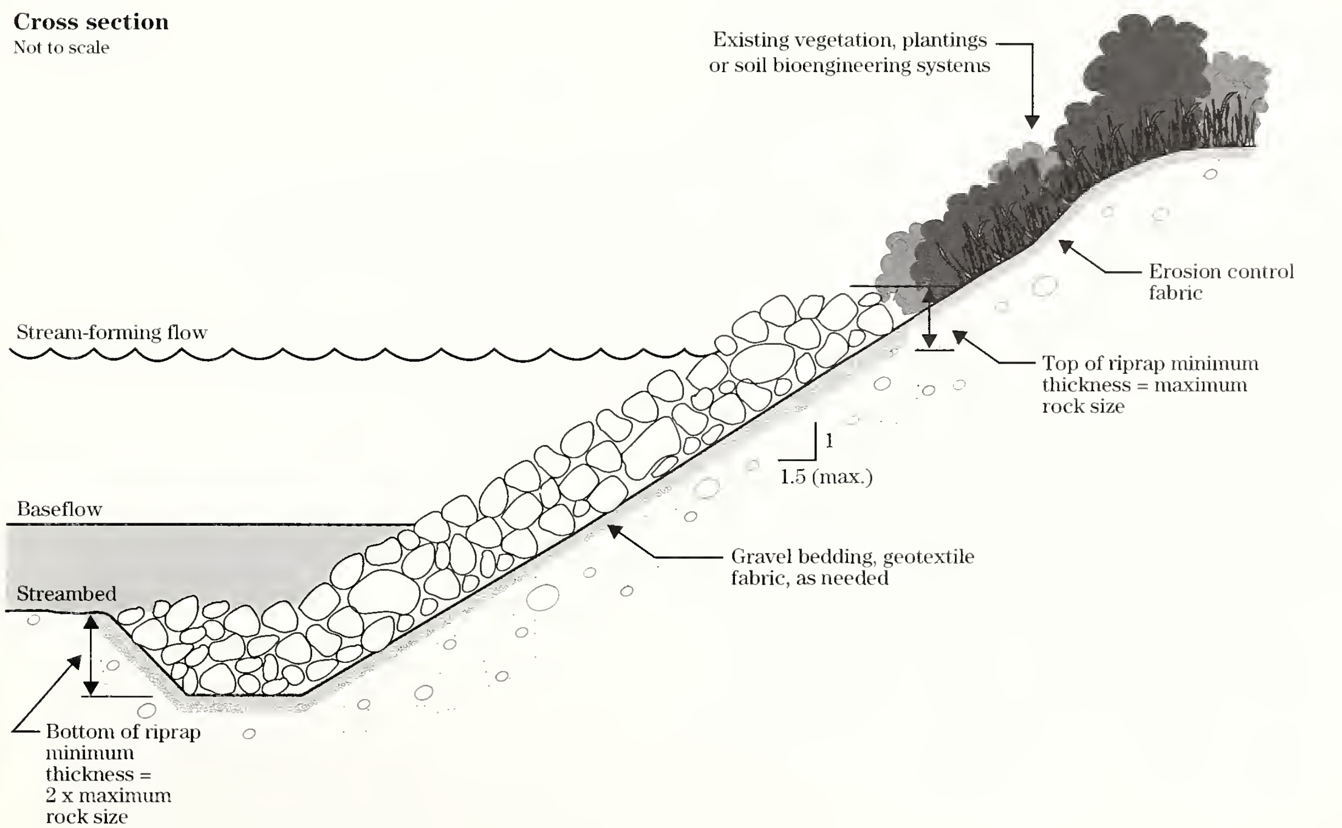
(vii) Rock riprap—Rock riprap, properly designed and placed, is an effective method of streambank protection (figs.16–32 and 16–33). The cost of quarrying, transporting, and placing the stone and the large quantity of stone that may be needed must be considered. Gabion baskets, concrete cellular blocks, or similar systems (figs. 16–34, 16–35a, 16–35b; and 16–42, 16–43) can be an alternative to rock riprap under many circumstances.

Applications and effectiveness
- Provides long-term stability.
- Has structural flexibility. It can be designed to self-adjust to eroding foundations.
- Has a long life and seldom needs replacement.
- Is inert so does not depend on specific environmental or climatic conditions for success.
- May be designed for high velocity flow conditions.

Construction guidelines
Inert materials—Cobbles and gravel obtained from the stream bed should not be used to armor streambanks unless the material is so abundant that its removal will not reduce habitat for benthic organisms and fish. Material forming an armor layer that protects the bed from erosion should not be removed. Use of stream cobble and gravel may require permission from state and local agencies.

Removing streambed materials tends to destroy the diversity of physical habitat necessary for optimum fish production, not only in the project area, but upstream and downstream as well. Construction activities often create channels of uniform depth and width in which water velocities increase. Following disruption of the existing streamflow by alteration of the stream channel, further damage results as the stream seeks to reestablish its original meander pattern.

Figure 16–32 Rock riprap details



Upstream, the stream may seek to adjust to the new gradient by actively eroding or grading its banks and bed. The eroded material may be deposited in the channel downstream from the alteration causing additional changes in flow pattern. The downstream channel will then also adjust to the new gradient and increased streamflow velocity by scour and bank erosion or further deposition.

Rock riprap on streambanks is affected by the hydrodynamic drag and lift forces created by the velocity of flow past the rock. Resisting the hydrodynamic effects are the force components resulting from the submerged weight of the rock and its geometry. These forces must be considered in any analytical procedure for determining a stable rock size. Channel alignment, surface roughness, debris and ice impact, rock gradation, angularity, and placement are other factors that must be considered when designing for given site conditions.

Numerous methods have been developed for designing rock riprap. Nearly all use either an allowable velocity or tractive stress methodology as the basis for determining a stable rock size. Table 16–2 lists several accepted procedures currently used in the NRCS. The table provides summary information and references where appropriate. Two of the more direct methods of obtaining a rock size are included in appendix 16A. All four methods listed in the table provide the user with a design rock size for a given set of input parameters. The first time user is advised to use more than one method in determining rock size. Availability of rock and experience of the designer continue to play important roles in determining the appropriate size rock for any given job.

Figure 16–33 Rock riprap revetment system

A well graded rock provides the greatest assurance of stability and long-term protection. Poorly graded rock results in weak areas where individual stones are subject to movement and subsequent revetment failure. Satisfactory gradation limits and thickness of the rock riprap can be determined from the basic stone size. Figure 16A–3 in appendix 16A can help determine rock gradation limits for any calculated basic rock size (D_{50}, D_{75}, and so forth).

The void space between rocks in riprap is generally many times greater than the void space in existing bank materials. A transition zone serves two purposes:

- Distributes the weight of rock to the underlying soil.
- Prevents movement and loss of fine grained soil into the large void spaces of the riprap.

The transition zone can be designed as a filter, bedding, or geotextile. The bank soils, bank seepage, and rock gradation and thickness are factors to consider when determining the transition material.

Bedding material is generally a pit run sand-gravel mixture. Bedding is suitable for those sites where bank materials are plastic and forces can be considered external, that is, forces acting on the bedding result only from the action of flow past or over the rock riprap. Bedding is not recommended for conditions where flow occurs through the rock (as on steep slopes), where subject to wave action, or where flow velocity exceeds 10 feet per second.

Table 16–2 Methods for rock riprap protection

Method (reference)	Basis for rock size	Procedure	Comments
Isbash Curve Appendix 16A (reprint from SCS Engineering Field Manual, chapter 16, 1969).	Allowable velocity—Curve developed from Isbash work.	Use design velocity and curve to determine basic rock size (D_{100}).	Use judgment to factor in site conditions. The basic stone weight is often doubled to account for debris.
FWS-Lane Appendix 16A (reprint from SCS Engineering Design Standards—Far West States, 1970).	Tractive stress—Monograph developed from Lane's work.	Enter monograph with channel hydraulic and physical data to solve for basic rock size (D_{75}).	Easy to use procedure. Generally results in a conservative rock size.
COE Method Corps of Engineers, EM 1110-2-1601, 7/91, Hydraulic Design of Flood Control Channels.	Allowable velocity—Basic equation developed by COE from study of models and comparison to field data.	Use equation or graphs and site physical and hydraulic data to determine basic rock size (D_{30}).	Detailed procedure can be used on natural or prismatic channels.
Federal Highway Administration Hydraulic Engineering Circular No. 11, Design of Riprap Revetment (1989).	Tractive Force Theory—Uses velocity as a primary design parameter.	Use equation with known site data and user determined stability factor to solve for basic rock size (D_{50}).	Stability factor requires user judgment of site conditions.

A filter is a graded granular material designed to prevent movement of the bank soil. A filter is recommended where bank materials are nonplastic, seepage forces exist, or where bedding is not adequate protection for the external forces as noted above. The site should be evaluated for potential seepage pressures from existing or seasonal water table, rapid fluctuations in streamflow (rapid drawdown), surface runoff, or other factors. In critical applications or where experience indicates problems with the loss of bank material under riprap, use chapter 26, part 633 of the NRCS National Engineering Handbook, January 1994, for guidance in designing granular filters.

Nonwoven geotextiles are widely used as a substitute for bedding and filter material. Availability, cost, and ease of placement are contributing factors. For guidance in selection of the proper geotextile, refer to NRCS Design Note 24, *Guide to Use of Geotextile.*

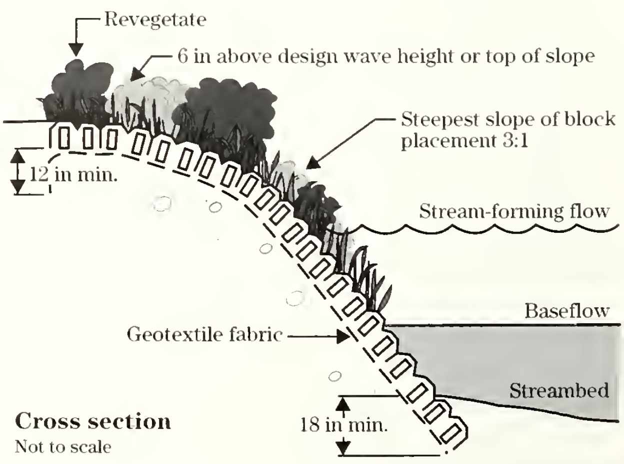
Installation

- Minimum thickness of the riprap should at least equal the maximum rock size at the top of the revetment. The thickness is often increased at the base of the revetment to two or more times the maximum rock size.
- The toe for rock riprap must be firmly established. This is important where the stream bottom is unstable or subject to scour during flood flows.
- Banks on which riprap is to be placed should be sloped so that the pressure of the stone is mainly against the bank rather than against the stone in the lower courses and toe. This slope should not be steeper than 1.5:1. The riprap should extend up the bank to an elevation at which vegetation will provide adequate protection.
- A filter or bedding must be placed between the riprap and the bank except in those cases where the material in the bank to be protected is determined to be a suitable bedding or filter material. The filter or bedding material should be at least 6 inches thick.
- A nonwoven geotextile may be used in lieu of a bedding or filter layer under the rock riprap. The geotextile material must maintain intimate contact with the subsurface. Geotextile that can move with changes in seepage pressure or external forces permits soil particle movement and can result in plugging of the geotextile. A 3-inch layer of bedding material over the geotextile prevents this movement.
- Hand-placing all rock in a revetment should seldom, if ever, be necessary. While the revetment may have a somewhat less finished look, it is adequate to dump the rock and rearrange it with a minimum of hand labor. However, the rock must be dumped in a manner that will not separate small and large stones or cause damage to the filter fabrics. The finished surface should not have pockets of finer materials that would flush out and weaken the revetment. Sufficient hand placing and chinking should be done to provide a well-keyed surface.

The Engineering Field Handbook, Chapter 17, Construction and Construction Materials, has additional information on riprap construction and materials.

Manufacturers have developed design recommendations for various flow and soil conditions. Their recommendations are good references in use of gabions, cellular blocks, and similar systems.

Figure 16–34 Concrete cellular block details



Cross section
Not to scale

Figure 16–35a Concrete cellular block system before backfilling

Figure 16–35b Concrete cellular block system several years after installation

(viii) Coconut fiber rolls—Coconut fiber rolls are cylindrical structures composed of coconut husk fibers bound together with twine woven from coconut (figs. 16–36, 16–37a, and 16–37b). This material is most commonly manufactured in 12-inch diameters and lengths of 20 feet. It is staked in place at the toe of the slope, generally at the stream-forming flow stage.

Applications and effectiveness

- Protect slopes from shallow slides or undermining while trapping sediment that encourages plant growth within the fiber roll.
- Flexible, product can mold to existing curvature of streambank.
- Produce a well-reinforced streambank without much site disturbance.
- Prefabricated materials can be expensive.
- Manufacturers estimate the product has an effective life of 6 to 10 years.

Construction guidelines

- Excavate a shallow trench at the toe of the slope to a depth slightly below channel grade.
- Place the coconut fiber roll in the trench.
- Drive 2 inch x 2 inch x 36 inch stakes between the binding twine and coconut fiber. Stakes should be placed on both sides of the roll on 2 to 4 feet centers depending upon anticipated velocities. Tops of stakes should not extend above the top of the fiber roll.
- In areas that experience ice or wave action, notch outside of stakes on either side of fiber roll and secure with 16-gauge wire.

Figure 16–36 Coconut fiber roll details

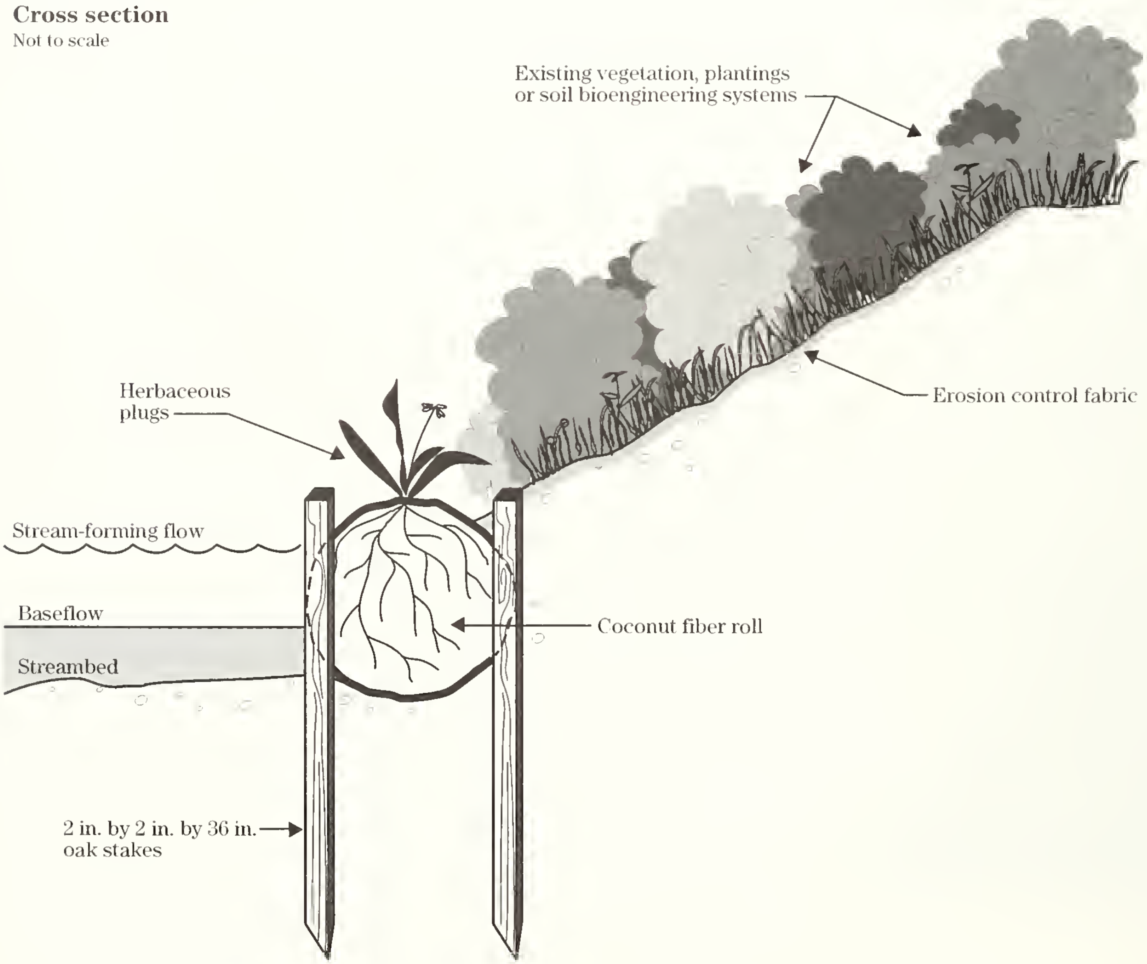


Figure 16–37a Coconut fiber roll

Figure 16–37b Coconut fiber roll system

- Backfill soil behind the fiber roll.
- If conditions permit, rooted herbaceous plants may be installed in the coconut fiber.
- Install appropriate vegetation or soil bioengineering systems upslope from fiber roll.

(ix) Stream jetties—Jetties are short dike-like structures that project from a streambank into a stream channel. They may consist of one or more structures placed at intervals along the bank to be protected. Most are constructed to the top of the bank and can be oriented either upstream, downstream, or perpendicular to the bank (figs. 16–38 and 16–39).

Jetties deflect or maintain the direction of flow through and beyond the reach of stream being protected. In function and design, jetties change the direction of flow by obstructing and redirecting the streamflow. Their design and construction require specialized skills. A fluvial geomorphologist, engineer, or other qualified discipline with knowledge of open channel hydraulics should be consulted for specific considerations and guidelines.

Applications and effectiveness
- Used successfully in a wide variety of applications in all types of rivers and streams.
- Effective in controlling erosion on bends in river and stream systems.
- Can be augmented with vegetation or soil bioengineering systems in some situations; i.e., deposited material upstream of jetties.
- May develop scour holes just downstream and off the end of the jetties.
- Can be complex and expensive.

Construction guidelines
Inert materials—Rock filled jetties are the most common, however, other materials are used including timber, concrete, gabions, and rock protected earth.

Installation
- Use a D_{50} size rock equal to 1.5 to 2 times the d_{50} size determined from rock riprap design methods for bank full flow condition.
- Size and space jetties so that flow passing around and downstream from the outer end will intersect the next jetty before intersecting the eroding bank. The length varies but should not unduly constrict the channel. Rock jetties typically have 2:1 side slopes with an 8 to 12-foot top width and 2:1 end slope.
- Space jetties to account for such characteristics as stream width, stream velocity, and radius of curvature. Typical spacing is 2 to 5 times the jetty length.
- Construct jetties with a level top or a downward slope to the outer end (riverward). The top of the jetty at the bank should be equal to the bank height.
- Orient jetties either perpendicular to the streambank or angled upstream or downstream. Perpendicular and downstream orientation are the most common.
- Tie jetties securely back into the bank and bed to prevent washout along the bank and undercutting. Place rock a short distance on either side of the jetty along the bank to prevent erosion at this critical location. The base of the jetty should be keyed into the bed a minimum depth equal to the D_{100} rock size.

Figure 16–38 Stream jetty details

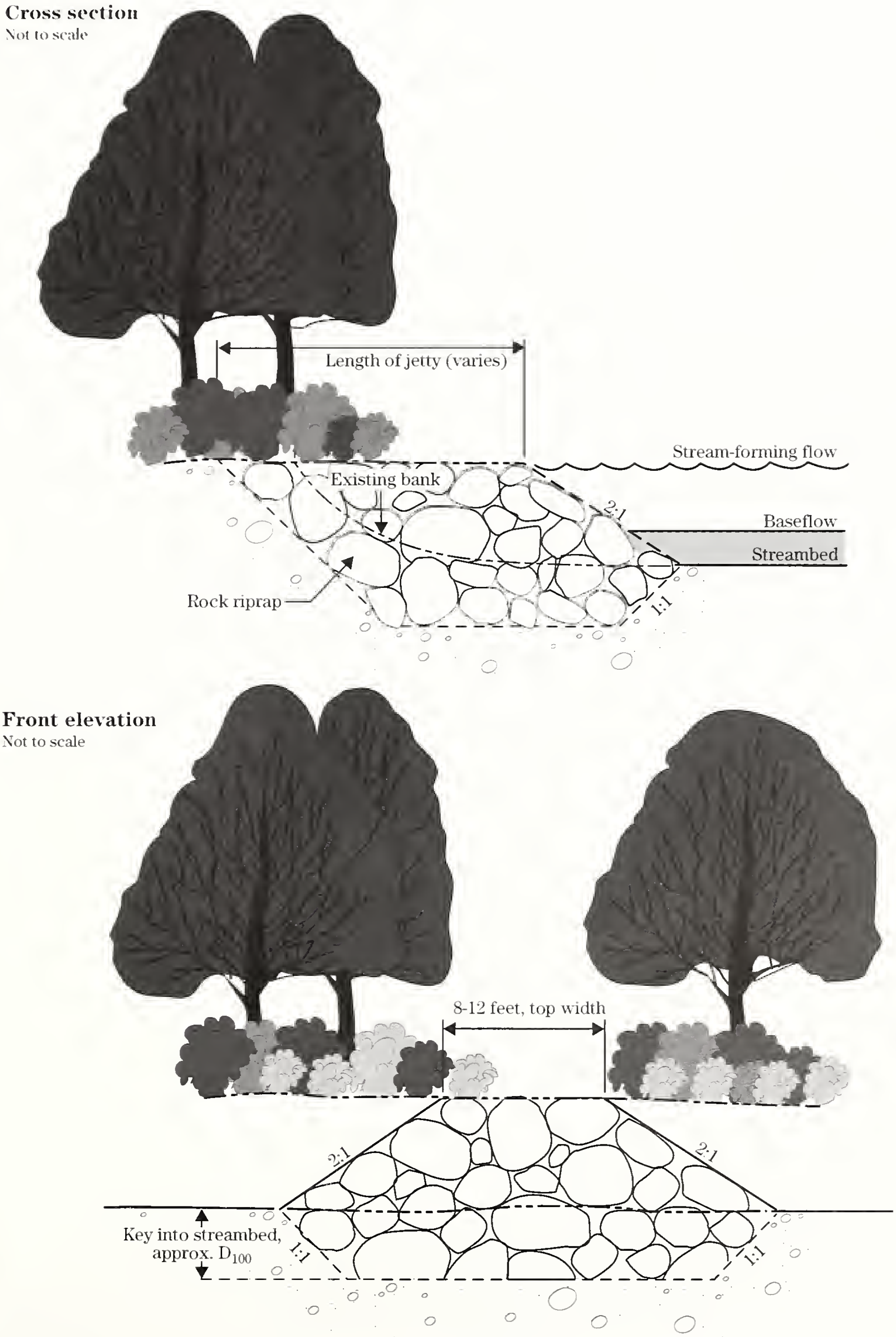


Figure 16–39a Stream jetty placed to protect railroad bridge

Figure 16–39b Long-established vegetated stream jetty, with deposition in foreground

(x) Stream barbs—Stream barbs are low rock sills projecting out from a streambank and across the stream's thalweg to redirect streamflow away from an eroding bank (figs.16–40 and 16–41). Flow passing over the barb is redirected so that the flow leaving the barb is perpendicular to the barb centerline. Stream barbs are always oriented upstream.

Application and effectiveness

- Used in limited applications and range of applicability is unclear.
- Effective in control of bank erosion on small streams.
- Require less rock and stream disturbance than jetties.
- Improve fish habitat (especially when vegetated).
- Can be combined with soil bioengineering practices.
- Can be complex and expensive.

Construction guidelines

Inert materials—Stream barbs require the use of large rock.

Installation

- Use a D_{50} size rock equal to two times the d_{50} size determined from rock riprap design methods for bank full flow condition. The maximum rock size (D_{100}) should be about 1.5 to 2 times the D_{50} size. The minimum rock size should not be less than $.75D_{50}$.
- Key the barb into the stream bed to a depth approximately D_{100} below the bed.
- Construct the barb above the streambed to a height approximately equal to the D_{100} rock, but generally not over 2 feet. The width should be at least equal to 3 times D_{100}, but not less than a typical construction equipment width of 8 to 10 feet. Construction of barbs can begin at the streambank and proceed streamward using the barb to support construction equipment.
- Align the barb so that the flow off the barb is directed toward the center of the stream or away from the bank. The acute angle between the barb and the upstream bank typically ranges from 50 to 80 degrees.
- Ensure that, at a minimum, the barb is long enough to cross the stream flow low thalweg.
- Space the barbs apart from 4 to 5 times the barb's length. The specific spacing is dependent on finding the point at which the streamflow leaving the barb intersects with the bank.

Figure 16–40 Stream barb details

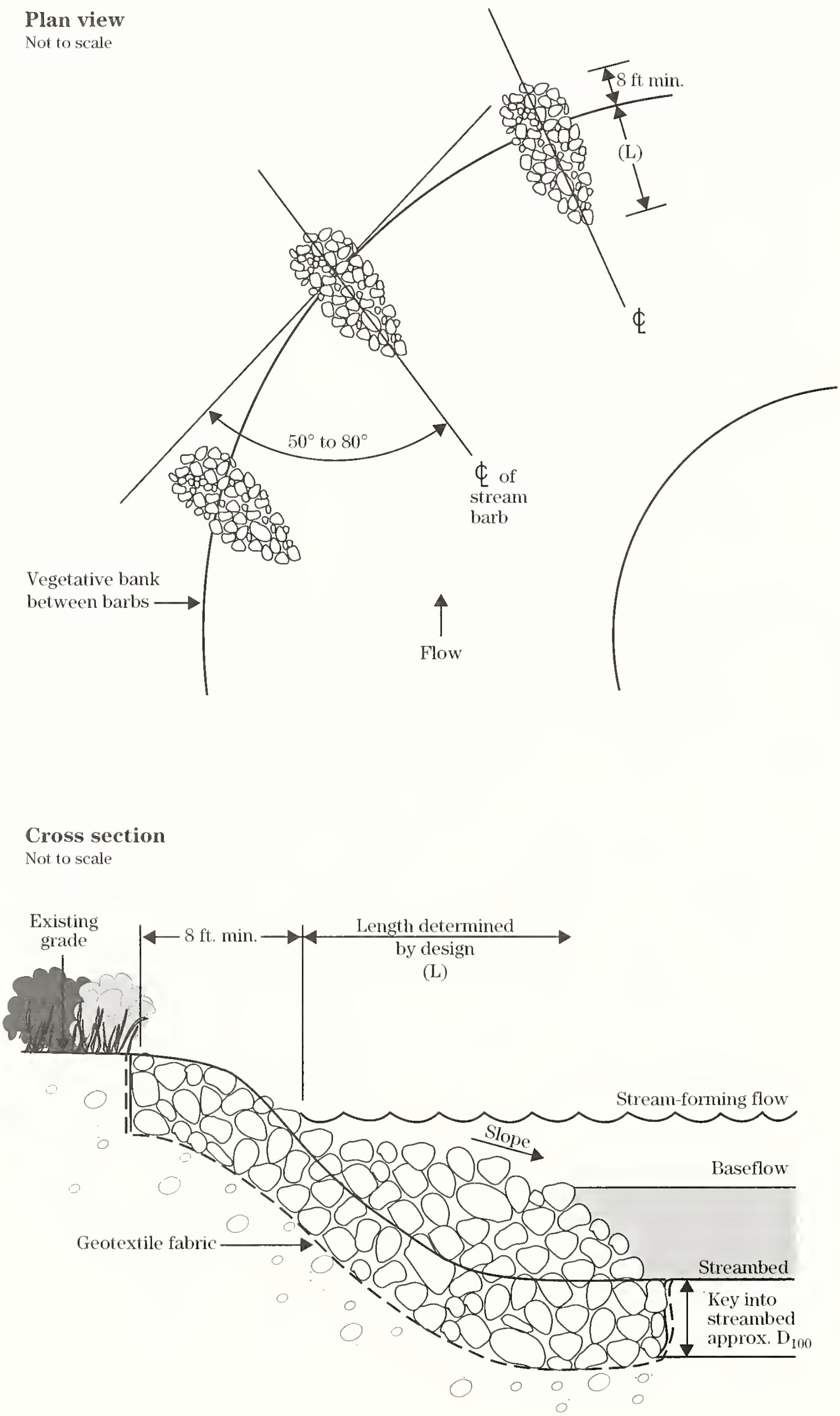


Figure 16–41 Stream barb system

(xi) Rock gabions—Rock gabions begin as rectangular containers fabricated from a triple twisted, hexagonal mesh of heavily galvanized steel wire. Empty gabions are placed in position, wired to adjoining gabions, filled with stones, and then folded shut and wired at the ends and sides. NRCS Construction Specification 64, Wire Gabions, provides detailed information on their installation.

Vegetation can be incorporated into rock gabions, if desired, by placing live branches on each consecutive layer between the rock-filled baskets (fig. 16–42 and 16–43). These gabions take root inside the gabion baskets and in the soil behind the structures. In time the roots consolidate the structure and bind it to the slope.

Applications and effectiveness

- Useful when rock riprap design requires a rock size greater than what is locally available.
- Effective where the bank slope is steep (typically greater than 1.5:1) and requires structural support.
- Appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Can be fabricated on top of the bank and then placed as a unit, below water if necessary.
- Lower initial cost than a concrete structure.
- Tolerate limited foundation movement.
- Have a short service life where installed in streams that have a high bed load. Avoid use where streambed material might abrade and cause rapid failure of gabion wire mesh.
- Not designed for or intended to resist large, lateral earth stresses. Should be constructed to a maximum of 5 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a more vertical structure is required.
- Where gabions are designed as a structural unit, the effects of uplift, overturning, and sliding must be analyzed in a manner similar to that for gravity type structures.
- Can be placed as a continuous mattress for slope protection. Slopes steeper than 2:1 should be analyzed for slope stability.
- Gabions used as mattresses should be a minimum of 9 inches thick for stream velocities of up to 9 feet per second. Increase the thickness to a minimum of 1.5 feet for velocities of 10 to 14 feet per second.

Construction guidelines

Live material sizes—When constructing vegetated rock gabions, branches should range from 0.5 to 2.5 inches in diameter and must be long enough to reach beyond the back of the rock basket structure into the backfill or undisturbed bank.

Inert materials—Galvanized woven wire mesh or galvanized welded wire mesh baskets or mattresses may be used. The baskets or mattresses are filled with sound durable rock that has a minimum size of 4 inches and a maximum of 9 inches. Gabions can be coated with polyvinyl chloride to improve their service life where subject to aggressive water or soil conditions.

Installation

- Remove loose material from the foundation area and cut or fill with compacted material to provide a uniform foundation.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure. This provides additional stability to the structure and ensures that the living branches root well for vegetated rock gabions.
- Place bedding or filter material in a uniformly graded surface. Compaction of materials is not usually required. Install geotextiles so that they lie smoothly on the prepared foundation.
- Assemble, place, and fill the gabions with rock. Be certain that all stiffeners and fasteners are properly secured.
- Place the gabions so that the vertical joints are staggered between the gabions of adjacent rows and layers by at least one-half of a cell length.
- Place backfill between and behind the wire baskets.
- For vegetated rock gabions, place live branch cuttings on the wire baskets perpendicular to the slope with the growing tips oriented away from the slope and extending slightly beyond the gabions. The live cuttings must extend beyond the backs of the wire baskets into the fill material. Place soil over the cuttings and compact it.
- Repeat the construction sequence until the structure reaches the required height.

- Where abrasive bedloads or debris can snag or tear the gabion wire, a concrete cap should be used to protect those surfaces subject to attack. A concrete cap 6 inches thick with 3 inches penetration into the basket is usually sufficient. The concrete for the cap should be placed after initial settlement has occurred.
- A filter is nearly always needed between the gabions and the foundation or backfill to prevent soil movement through the baskets. Geosynthetics can be used in lieu of granular filters for many applications, however, when drainage is critical, the fabric must maintain intimate contact with the foundation soils. A 3-inch layer of sand-gravel between the gabions and the filter material assures that contact is maintained.
- At the toe and up and downstream ends of gabion revetments, a tieback into the bank and bed should be provided to protect the revetment from undermining or scour.

Figure 16–42 Vegetated rock gabion details

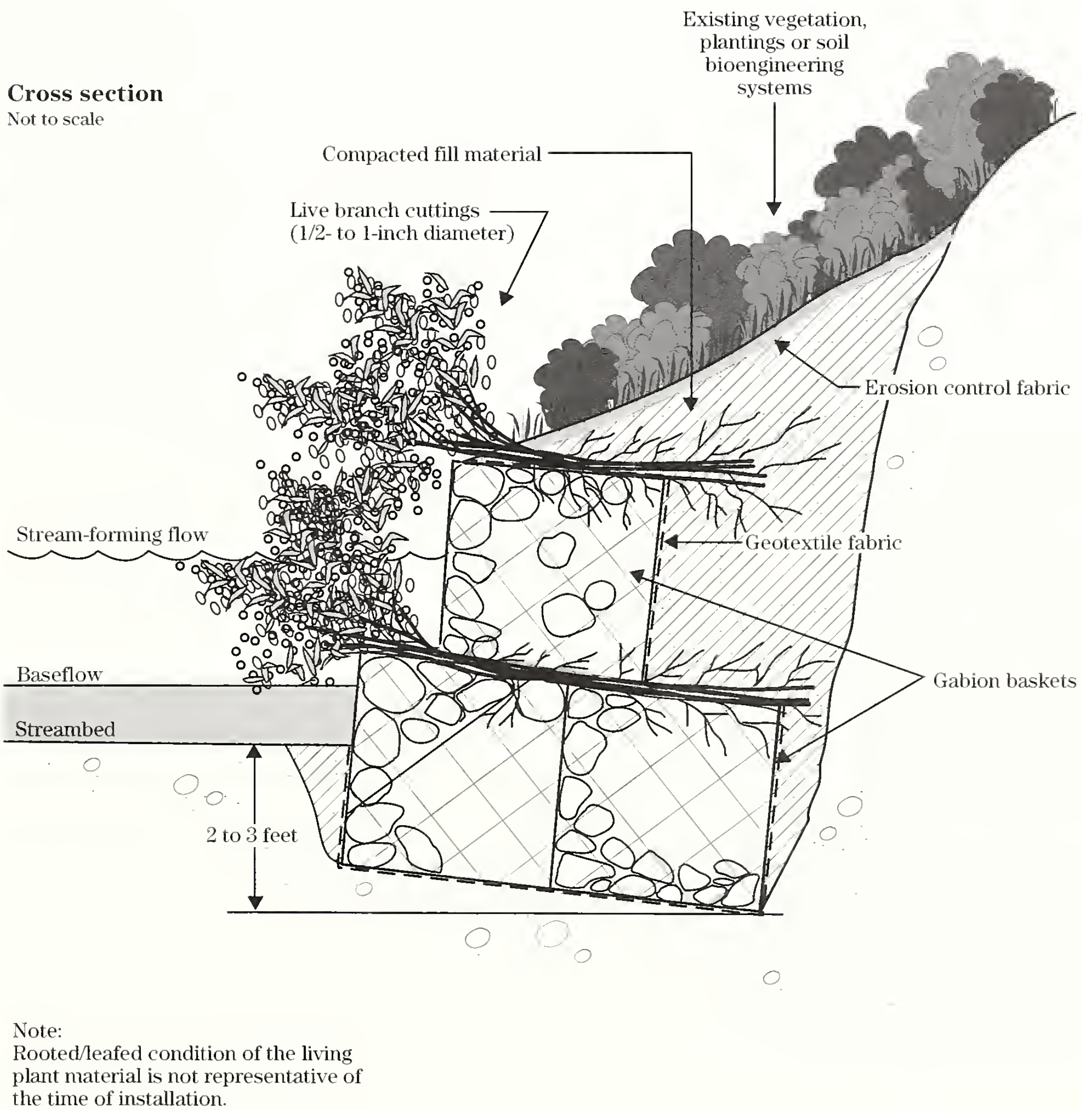


Figure 16–43 Vegetated rock gabion system (H.M. Schiechtl photo)

650.1602 Shoreline protection

(a) General

Shoreline erosion results primarily from erosive forces in the form of waves generally perpendicular to the shoreline. As a wave moves toward shore, it begins to drag on the bottom, dissipating energy. This eventually causes it to break or collapse. This major turbulence stirs up material from the shore bottom or erodes it from banks and bluffs. Fluctuating tides, freezing and thawing, floating ice, and surface runoff from adjacent uplands may also cause shorelines to erode.

(1) Types of shoreline protection

Systems for shoreline protection can be living or nonliving. They consist of vegetation, soil bioengineering, structures, or a combination of these.

(2) Planning for shoreline protection measures

The following items need to be considered for shoreline protection in addition to the items listed earlier in this chapter for planning streambank protection measures:

- Mean high and low water levels or tides.
- Potential wave parameters.
- Slope configuration above and below waterline.
- Nature of the soil material above and below water level.
- Evidence of littoral drift and transport.
- Causes of erosion.
- Adjacent land use.
- Maintenance requirements.

(b) Design considerations for shoreline protection

(1) Beach slope

Slopes should be determined above and below the waterline. The slope below waterline should be representative of the slope for a distance of at least 50 feet.

(2) Offshore depth and wave height

Offshore depth is a critical factor in designing shoreline protection measures. Structures that must be constructed in deep water, or in water that may become deep, are beyond the scope of this chapter. Other important considerations are the dynamic wave height acting in deep water (roughly, the total height of the wave is three times that visible) and the decreased wave action caused by shallow water. Effective fetch length also needs to be considered in determining wave height. Methods for computing wave height using fetch length are in NRCS Technical Releases 56 and 69.

(3) Water surface

The design water surface is the mean high tide or, in nontidal areas, the mean high water. This information may be obtained from tidal tables, records of lake levels, or from topographic maps of the reservoir site in conjunction with observed high and normal water lines along the shore.

(4) Littoral transport

The material being moved parallel to the shoreline in the littoral zone, under the influence of waves and currents should be addressed in groin design. It is important to determine that the supply of transport material is not coming from the bank being protected and the predominant direction of littoral transport. This information is used to locate structures properly with respect to adjacent properties and so that groins can fill most quickly and effectively. Another factor to be considered is that littoral transport often reverses directions with a change in season.

The rate of littoral transport and the supply are as important as the direction of movement. No simple ways to measure the supply are available. For the scope of this chapter, supply may be determined by observation of existing structures, sand beaches, auger samples of the sand above the parent material on the beach, and the presence of sandbars offshore. Other

considerations are existing barriers, shoreline configuration, and inlets that tend to push the supply offshore and away from the area in question. The net direction of transport is an important and complex consideration.

(5) Bank soil type

Determining the nature of bank soil material aids in estimating the rate of erosion. A very dense, heavy clay can offer more resistance to wave action than noncohesive materials, such as sand. A thin sand lens can result in erosion problems since it may be washed out when subjected to high tides or wave action for extended periods of time. The resulting void will no longer support the bank above it, causing it to break away.

(6) Foundation material

The type of existing foundation may govern the type of protection selected. For example, a rock bottom will not permit the use of sheet piling. If the use of riprap is being considered on a highly erodible foundation, a filter will be needed to prevent fine material from washing through the voids. A soft foundation, such as dredge spoil, may result in excessive flotation or movement of the structure in any direction.

(7) Adjacent shoreline and structures

Structures that might have an effect on adjacent shoreline or other structures must be examined carefully. End sections need to be adequately anchored to existing measures or terminated in stable areas.

(8) Existing vegetation

The installation of erosion control structures can have a detrimental effect upon existing vegetation unless steps are taken to prevent what is often avoidable site disturbance. Existing vegetation should be saved as an integral part of the erosion control system being installed.

(c) Protective measures for shorelines

The analysis and design of shoreline protection measures are often complex and require special expertise. For this reason the following discussion is limited to revetments, bulkheads, and groins no higher than 3 feet above mean high water, as well as soil bioengineering and other vegetative systems used alone or in combination with structural measures. Consideration must be given to the possible effects that erosion control measures can have on adjacent areas, especially estuarine wetlands.

(1) Groins

Groins are somewhat permeable to impermeable finger-like structures that are installed perpendicular to the shore. They generally are constructed in groups called groin fields, and their primary purpose is to trap littoral drift. The entrapped sand between the groins acts as a buffer between the incoming waves and shoreline by causing the waves to break on the newly deposited sand and expend most of their energy there (figs. 16–44 and 16–45).

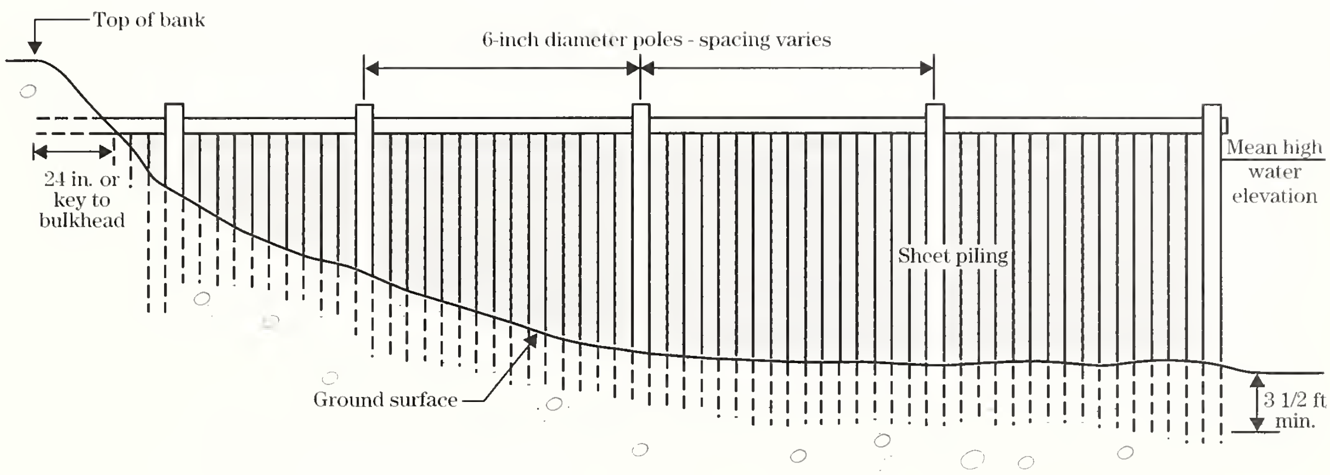
Applications and effectiveness

- Particularly dependent on site conditions. Groins are most effective in trapping sand when littoral drift is transported in a single direction.
- Filling the groin field with borrowed sand may be necessary, if the littoral transport is clay or silt rather than sand.
- Will not fill until all preceding updrift groins have been filled.

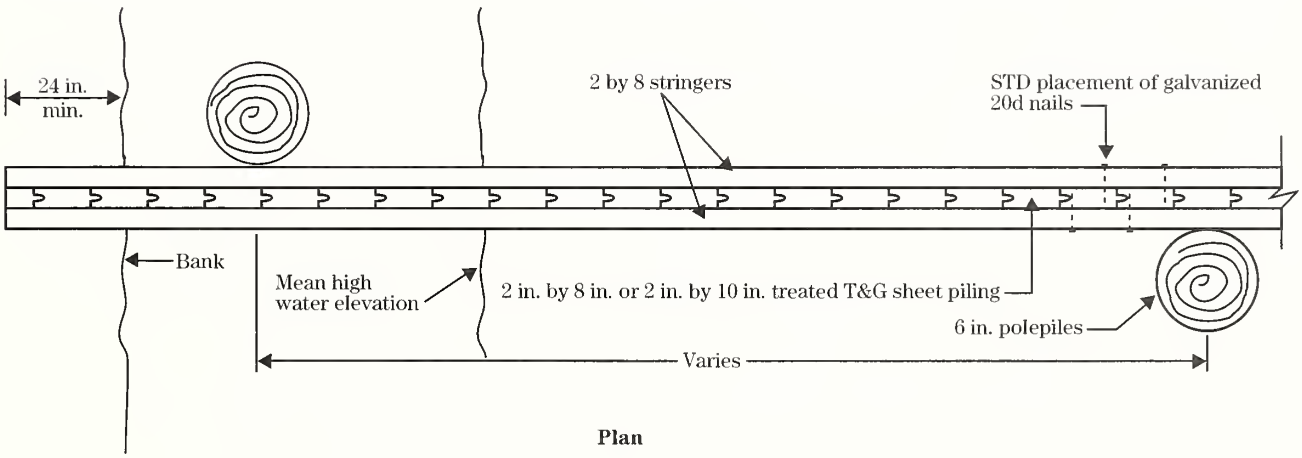
Construction guidelines

Inert materials—The most common type of structural groin is built of preservative-treated tongue and groove sheet piling.

Figure 16–44 Timber groin details



Cross section



Plan

Installation

- Groins must extend far enough into the water to retain desired amounts of sand. The distance between groins generally ranges from one to three times the length of the groin. When used in conjunction with bulkheads, the groins are usually shorter.
- Groins are particularly vulnerable to storm damage before they fill, so initially only the first three or four at the downdrift end of the system should be constructed.
- Install the second group of groins after the first has filled and the material passing around or over the groins has again stabilized the downdrift shoreline. This provides the means to verify or adjust the design spacing.
- Key the shoreward end of the groins into the shoreline bank for at least 2 feet or extend them to a bulkhead.
- Measure the groin height on the shoreline so that it will generally be at high tide or mean high water elevation plus 2 or 3 feet for wave surge height. Decrease the height seaward at a gradual rate to mean high water elevation.

Figure 16–45 Timber groin system

(3) Bulkheads

Bulkheads are vertical structures of timber, concrete, steel, or aluminum sheet piling installed parallel to the shoreline.

Applications and effectiveness

- Generally constructed where wave action will not cause excessive overtopping of the structure, which causes bank erosion to continue as though the bulkhead were not there.
- Scour at the base of the bulkhead also causes failure. The vertical face of the bulkhead redirects wave action to cause excessive scour at the toe of the structure unless it is protected.

Construction guidelines

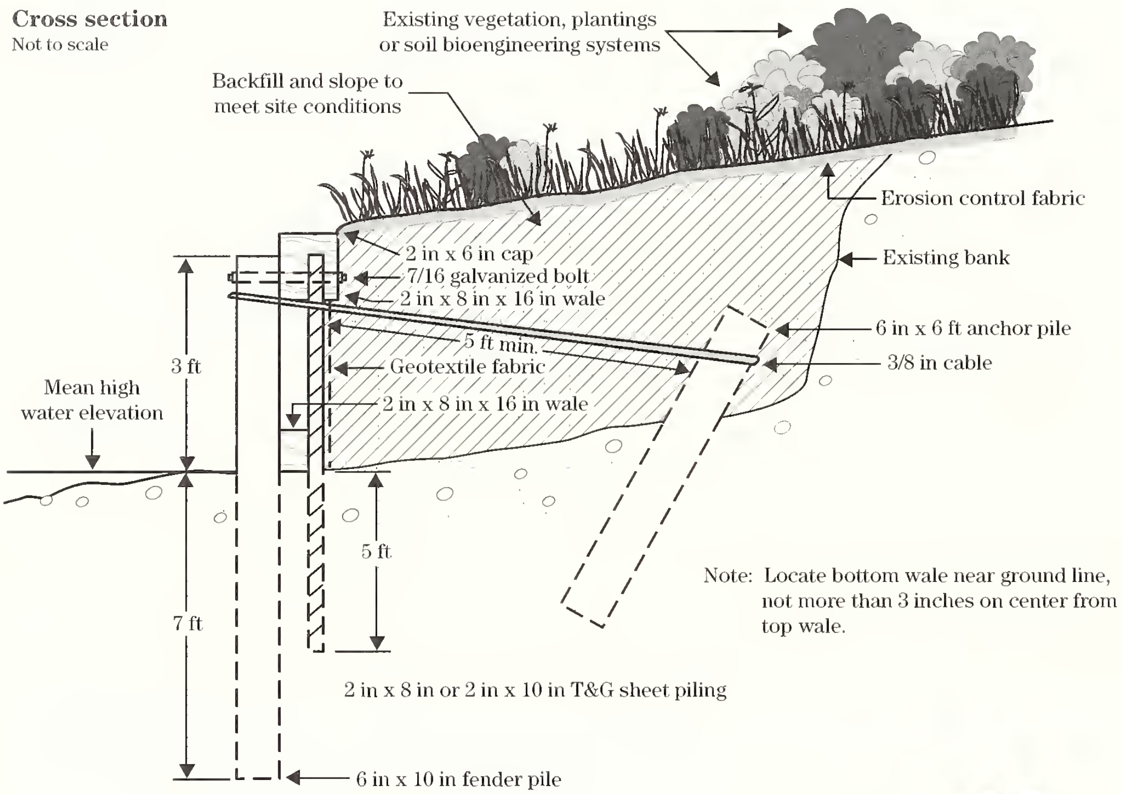
Inert materials—The most common materials used for bulkhead construction are timber (figs. 16–46 and 16–47), concrete (figs. 16–48 and 16–49), and masonry.

Installation

- Use environmentally compatible treated timber.
- Thickness and spacing of pilings, supports, cross member, and face boards must be engineered on a site-by-site basis.
- Pilings can be drilled, driven, or jetted depending on the foundation materials. Depth of piling must be at least equal to the exposed height below the point of maximum anticipated scour.
- Place stones or other appropriate materials at the base of the bulkhead to absorb wave energy.
- In salt water environments, use noncorrosive materials to the greatest extent possible.

Figure 16–46 Timber bulkhead system

Figure 16–47 Timber bulkhead details



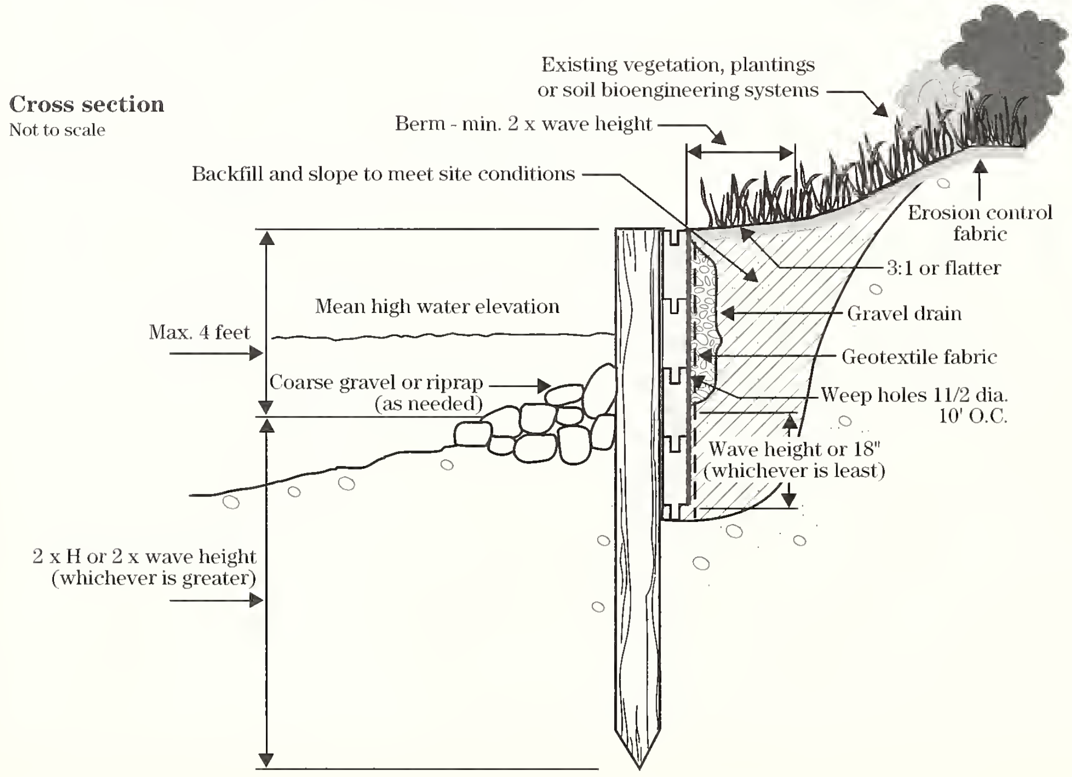
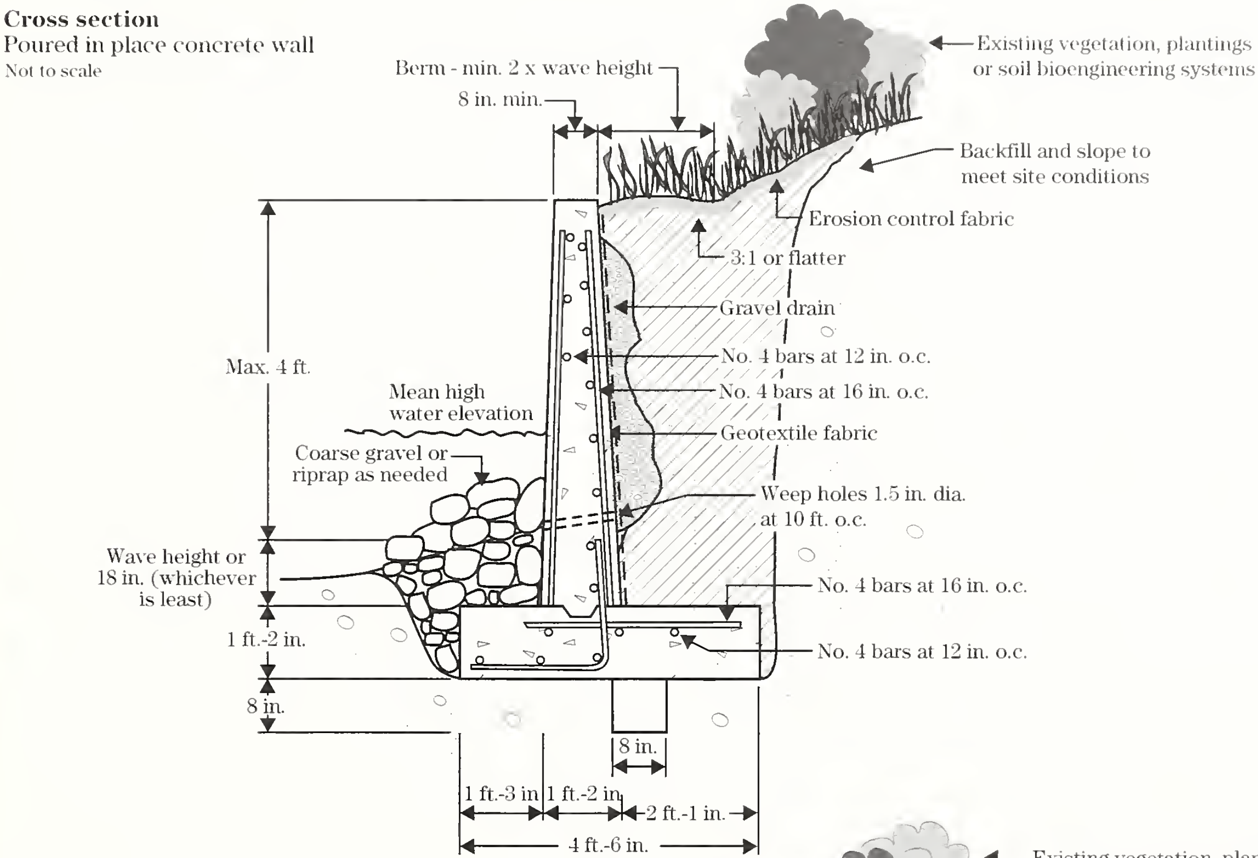


Figure 16–48 Concrete bulkhead details



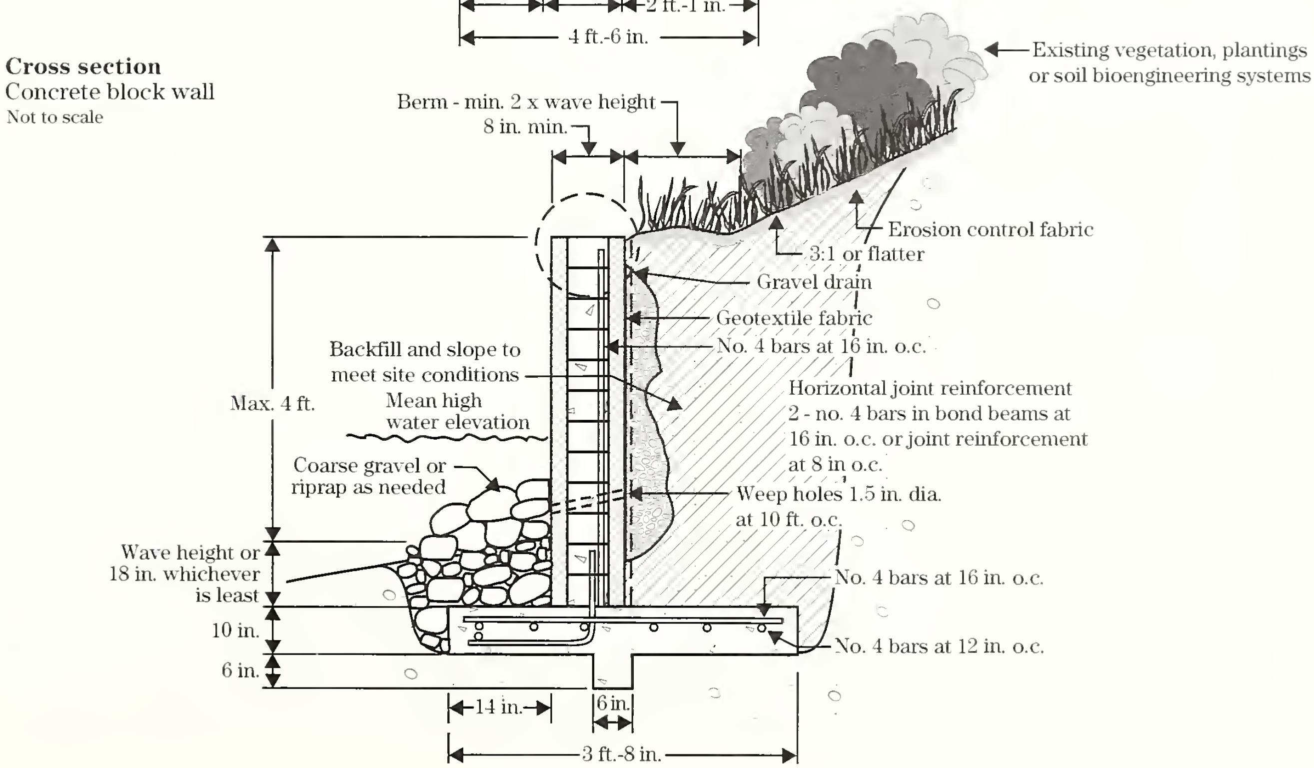


Figure 16–49 Concrete bulkhead system

(4) Revetments

Revetments are protective structures of rock, concrete, cellular blocks, or other material installed to fit the slope and shape of the shoreline (figs. 16–50 and 16–51).

Applications and effectiveness

- Flexible and not impaired by slight movement caused by settlement or other adjustments.
- Preferred to bulkheads where the possibility of extreme wave action exists.
- Local damage or loss of rock easily repaired.
- No special equipment required for construction.
- Subject to scour at the toe and flanking, thus filters are important and should always be considered.
- Complex and expensive.

Construction guidelines

- The size and thickness of rock revetments must be determined to resist wave action. NRCS Technical Release 69, *Rock Riprap for Slope Protection Against Wave Action*, provides guidance for size, thickness, and gradation.
- The base of the revetment must be founded below the scour depth or placed on nonerosive material.
- Angular stone is preferred for revetments. If rounded stone is used, increase the layer thickness by a factor of 1.5.
- Use a minimum thickness of 6-inch filter material under rock.
- If geotextile is used in place of granular filter, cover the geotextile with a minimum of 3inches of sand-gravel before placement of rock.

Figure 16–50 Concrete revetment (poured in place)

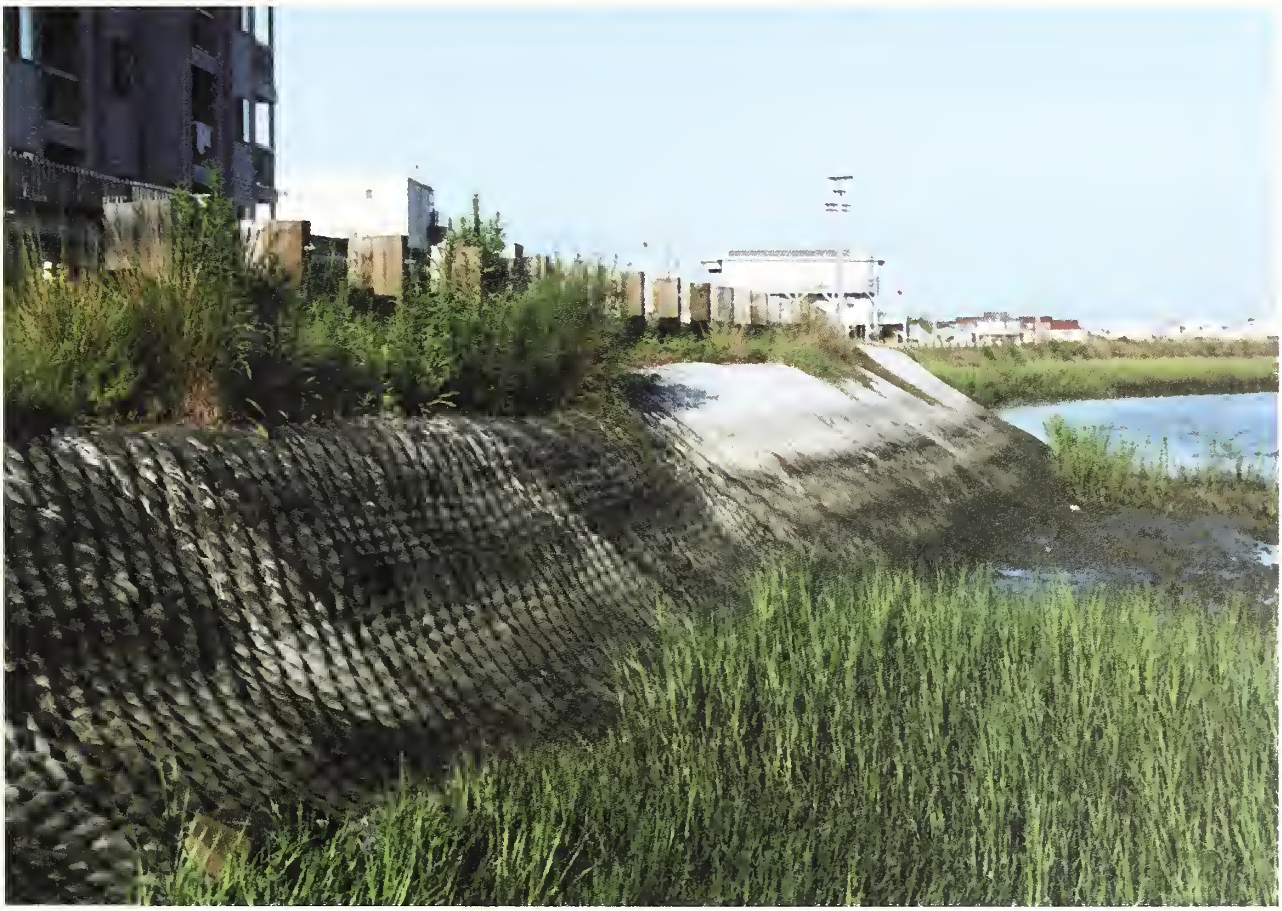


Figure 16–51 Rock riprap revetment

(5) Vegetative measures
If some vegetation exists on the shoreline, the shoreline problem may be solved with more vegetation. Determine if the vegetation disappeared because of a single, infrequent storm, or if plants are being shaded out by developing overstory trees and shrubs. In either case revegetation is a viable alternative. Consult local technical guides and plant material specialists for appropriate plant species and planting specifications. NRCS Technical Release 56, *Vegetative Control of Wave Action on Earth Dams*, provides additional guidance.

(6) Patching
A shoreline problem is often isolated and requires only a simple patch repair. Site characteristics that would indicate a patch solution may be appropriate include good overall protection from wave action, slight undercutting in spots with an occasional slide on the bank, and fairly good vegetative growth on the shoreline. The problems are often caused by boat wake or excessive upland runoff. Fill undercut areas with stone sandbags or grout-filled bags and repair with a grass transplant, reed clumps, branchpacking, vegetated geogrid, or vegetated riprap.

Slides that occur because of a saturated soil condition are best alleviated by providing subsurface drainage or a diversion. Leaning or slipping trees in the immediate slide area may need to be removed initially because of their weight and the forces they exert on the soil; however, once the saturated condition is remedied, disturbed areas should be revegetated with native trees, shrubs, grasses, and forbs to establish cover.

(7) Soil bioengineering systems
Soil bioengineering systems that are best suited to reducing erosion along shorelines are live stakes, live fascines, brushmattresses, live siltation, and reed clump constructions.

(i) Live stake—Live stakes offer no stability until they root into the shoreline area, but over time they provide excellent soil reinforcement. To reduce failure until root establishment occurs, installations may be enhanced with a layer of long straw mulch covered with jute mesh or, in more critical areas, a natural geotextile fabric.

Refer to streambank protection section of this chapter for appropriate applications and construction guidelines.

(ii) Live fascine—The live fascines previously described in this chapter work best in shoreline applications where the ground between them is also protected. Natural geotextiles, such as those manufactured from coconut husks, are strong, durable, and work well to protect the ground.

Construction guidelines
Live materials—Live cuttings as previously described for fabrication of live fascine bundles. Fabricate live fascine bundles approximately 8 inches in diameter. Live stakes should be about 3 feet long.

Inert materials—Dead stout stakes approximately 3 feet long to anchor well in loose sand. Jute mesh with long straw for low energy shorelines. Natural geotextile with long straw for higher energy shorelines.

Installation
The installation methods are similar to those discussed for live fascines, with the following variations:
- Excavate a trench approximately 10 inches wide and deep, beginning at one end of and parallel to the shoreline section to be repaired and extending to the other end.
- Spread jute mesh or geotextile fabric across the excavated trench and temporarily leave the remainder on the slope immediately above the trench.
- Place a live fascine bundle in the trench on top of the fabric and anchor with live and dead stout stakes.
- Spread long straw on the slope above the trench to the approximate location of the next trench to be constructed upslope.
- Pull the fabric upslope over the long straw and spread in the next excavated trench. Trenches should be spaced 3 to 5 feet apart and parallel to each other.
- Repeat the process until the system is in place over the treatment area.

(iii) Brushmattress—Brushmattresses for shorelines perform a similar function as those for streambanks. Therefore, effectiveness and construction guidelines are similar to those given earlier in this chapter, with the following additions.

Applications and effectiveness

- May be effective in lake areas that have fluctuating water levels since they are able to protect the shoreline and continue to grow.
- Able to filter incoming water because they also establish a dense, healthy shoreline vegetation.

Installation

- After the trench at the bottom has been dug and the mattress branches placed, the trench should be lined with geotextile fabric.
- Secure the live fascine, press down the mattress brush, and place the fabric on top of the brush.
- At this point, install the live and dead stout stakes to hold the brush in place. A few dead stout stakes may be used in the mattress branch and partly wired down before covering the fabric. This helps in the final steps of covering and securing the brush and the fabric.

(iv) Live siltation construction—Live siltation construction is similar to brushlayering except that the orientation of the branches are more vertical. Ideally live siltation systems are approximately perpendicular to the prevailing winds. The branch tips should slope upwards at 45 to 60 degrees. Installation is similar to brushlayering (see Engineering Field Handbook, chapter 18 for a more complete discussion of a brushlayer).

Live siltation branches that have been installed in the trenches serve as tensile inclusions or reinforcing units. The part of the brush that protrudes from the ground assists in retarding runoff and surface erosion from wave action and wind (figs. 16–52 and 16–53).

Applications and effectiveness

Live siltation systems provide immediate erosion control and earth reinforcement functions, including:

- Providing surface stability for the planting or establishment of vegetation.
- Trapping debris, seed, and vegetation at the shoreline.
- Reducing wind erosion and surface particle movement.
- Drying excessively wet sites through transpiration.
- Promoting seed germination for natural colonization.
- Reinforcing the soil with unrooted branch cuttings.
- Reinforcing the soil as deep, strong roots develop and adding resistance to sliding and shear displacement.

Construction guidelines

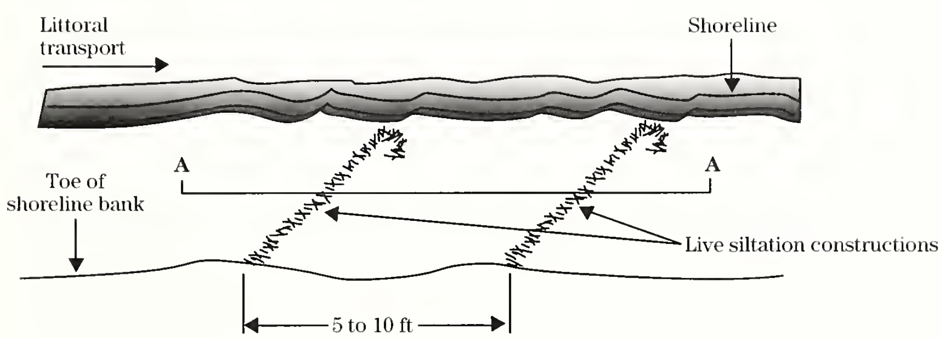
Live material—Live branch cuttings 0.5 to 1 inch in diameter and 4 to 5 feet long with side branches intact.

Installation

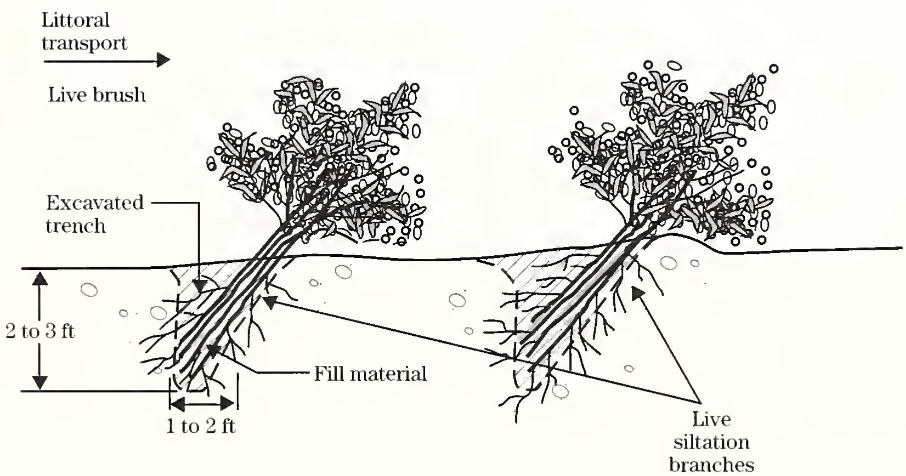
- Beginning at the toe of the shoreline bank to be treated, excavate a trench 2 to 3 feet deep and 1 to 2 feet wide, with one vertical side and the other angled toward the shoreline.
- Parallel live siltation rows should vary from 5 to 10 feet apart, depending upon shoreline conditions and stability required. Steep, unstable and high energy sites require closer spacing.

Figure 16–52 Live siltation construction details

Plan
Not to scale



Section A-A



Note: Rooted/leafed condition of the living plant material is not respresentative of the time of installation.

Figure 16–53 Live siltation construction system (Robbin B. Sotir & Associates photo)

(v) Reed clump—Reed clump installations consist of root divisions wrapped in natural geotextile fabric, placed in trenches, and staked down. The resulting root mat reinforces soil particles and extracts excess moisture through transpiration. Reed clump systems are typically installed at the water's edge or on shelves in the littoral zone (fig. 16–54 and 16–55).

Applications and effectiveness

- Reduces toe erosion and creates a dense energy-dissipating reed bank area.
- Offers relatively inexpensive and immediate protection from erosion.
- Useful on shore sites where rapid repair of spot damage is required.
- Retains soil and transported sediment at the shoreline.
- Reduces a long beach wash into a series of shorter sections capable of retaining surface soils.
- Enhances conditions for natural colonization and establishment of vegetation from the surrounding plant community.
- Grows in water and survives fluctuating water levels.

Construction guidelines

Live materials—The reed clumps should be 4 to 8 inches in diameter and taken from healthy water-dependent species, such as arrowhead, cattail, or water iris. They may be selectively harvested from existing natural sites or purchased from a nursery.

Wrap reed clumps in natural geotextile fabric and bind together with twine. These clumps can be fabricated several days before installation if they are kept moist and shaded.

Inert materials—Natural geotextile fabric, twine, and 3- to 3.5-foot-long dead stout stakes are required.

Installation

- Reed root clumps are either placed directly into fabric-lined trenches or prefabricated into rolls 5 to 30 feet long. With the growing tips pointing up, space clumps every 12 inches on a 2- to 3-foot-wide strip of geotextile fabric to fabricate the rolls. The growing buds should all be oriented in the same upright direction for correct placement into the trench.
- Wrap the fabric from both sides to overlap the top, leaving the reed clumps exposed and bound with twine between each plant.
- Beginning at and parallel to the water's edge, excavate a trench 2 inches wider and deeper than the size of the prefabricated reed roll or reed clumps.
- To place reed clumps directly into trenches, first line the trench with a 2- to 3-foot-wide strip of geotextile fabric before spreading a 1-inch layer of highly organic topsoil over it at the bottom of the trench. Next, center the reed clumps on 12-inch spacing in the bottom of the trench. Fill the remainder of the trench between and around reed clumps with highly organic topsoil, and compact. Wrap geotextile fabric from each side to overlap at the top and leave the reed clumps exposed before securing with dead stout stakes spaced between the clumps. Complete the installation by spreading previously excavated soil around the exposed reed clumps to cover this staked fabric.
- To use the prefabricated reed clump roll, place it in the excavated trench, secure it with dead stout stakes, and backfill as described above.
- Repeat the above procedure by excavating additional parallel trenches spaced 3 to 6 feet apart toward the shoreline. Place the reed clumps from one row to the next to produce a staggered spacing pattern.

Figure 16–54 Reed clump details

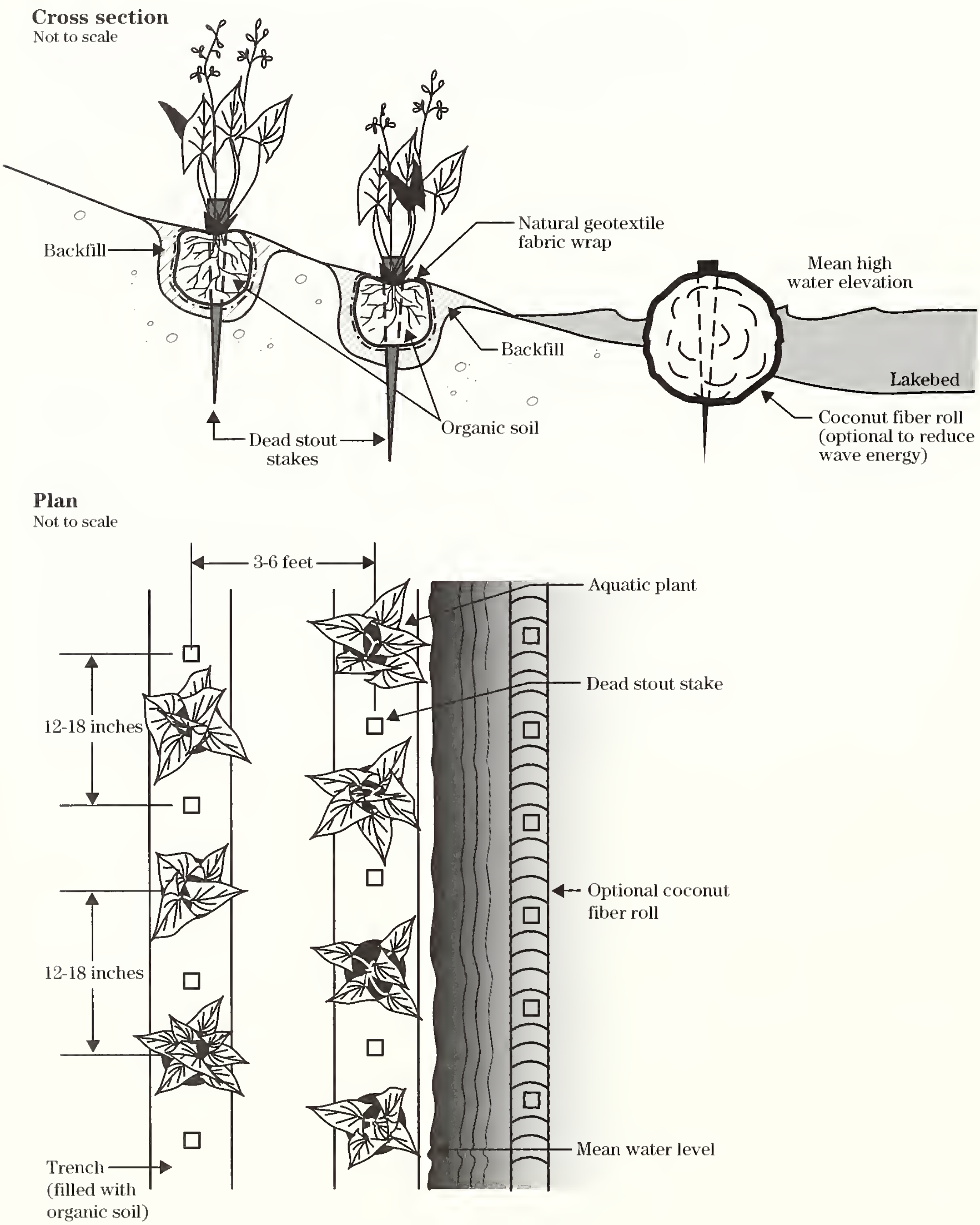


Figure 16–55a Installing dead stout stakes in reed clump system (Robbin B. Sotir & Associates photo)

Figure 16–55b Completing installation of reed clump system (Robbin B. Sotir & Associates photo)

Figure 16–55c Established reed clump system (Robbin B. Sotir & Associates photo)

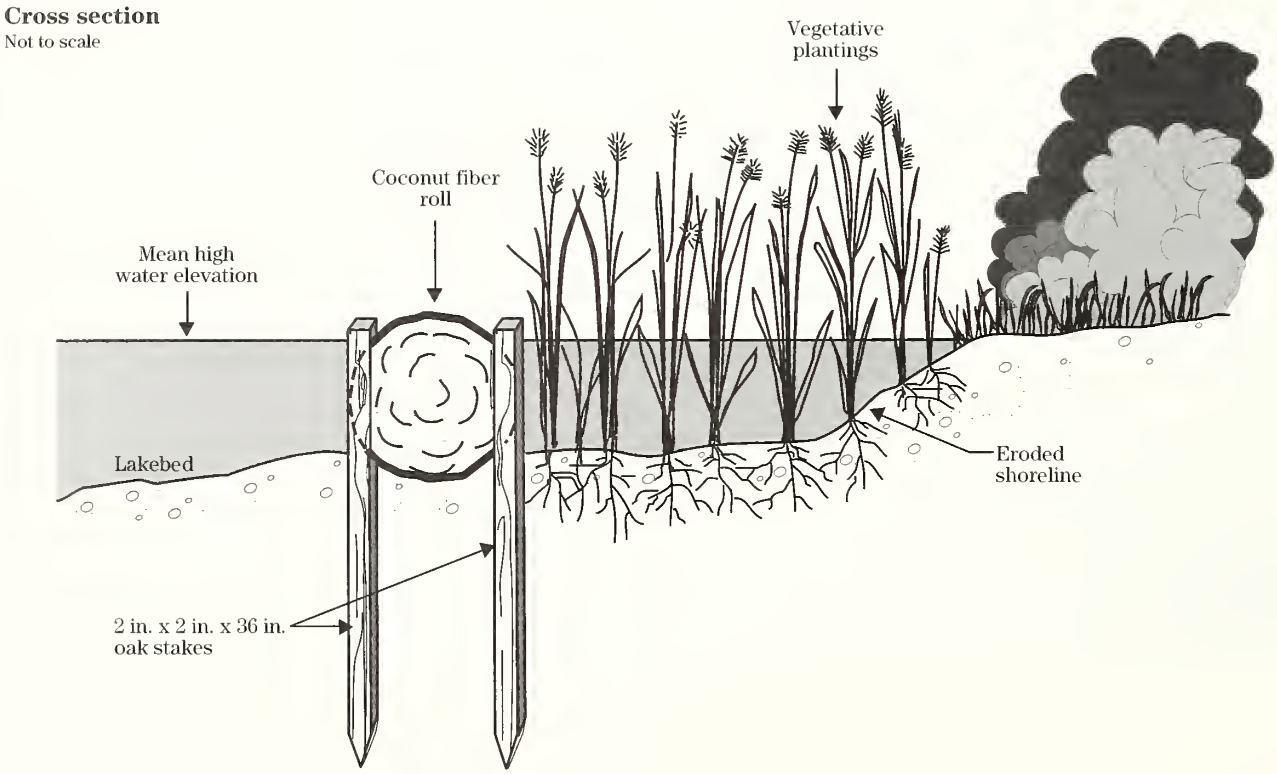
(8) Coconut fiber roll

Coconut fiber rolls are cylindrical structures composed of coconut fibers bound together with twine woven from coconut (figs. 16–56 and 16–57). This material is most commonly manufactured in 12-inch diameters and lengths of 20 feet. The fiber rolls function as breakwaters along the shores of lakes and embayments. In addition to reducing wave energy, this product can help contain substrate and encourage development of wetland communities.

Applications and effectiveness

- Effective in lake areas where the water level fluctuates because it is able to protect the shoreline and encourage new vegetation.
- Flexible, can be molded to the curvature of the shoreline.
- Prefabricated materials can be expensive.
- Manufacturers estimate the product has an effective life of 6 to 10 years.

Figure 16–56 Coconut fiber roll details



Installation

- Fiber roll should be located off shore at a distance where the top of the fiber roll is exposed at low tide. In nontidal areas, the fiber roll should be placed where it will not be overtopped by wave action.
- Drive 2 inch x 2 inch stakes between the binding twine and the coconut fiber. Stakes should be placed on 4-foot centers and should not extend above the fiber roll.
- If desired, rooted cuttings can be installed between the coconut fiber roll and the shoreline.

Figure 16–57 Coconut fiber roll system

650.1603 References

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Glossary

Bankfull discharge Natural streams—The discharge that fills the channel without overflowing onto the flood plain.

Modified or entrenched streams—The streamflow volume and depth that is the 1- to 3-year frequency flow event.

The discharge that determines the stream's geomorphic planform dimensions.

Bar A streambed deposit of sand or gravel, often exposed during low-water periods.

Baseflow The ground water contribution of streamflow.

Bole Trunk of a tree.

Branchpacking Live, woody, branch cuttings and compacted soil used to repair slumped areas of streambanks.

Brushmattress A combination of live stakes, fascines, and branch cuttings installed to cover and protect streambanks and shorelines.

Bulkhead Generally vertical structures of timber, concrete, steel, or aluminum sheet piling used to protect shorelines from wave action.

Channel A natural or manmade waterway that continuously or intermittently carries water.

Cohesive soil A soil that, when unconfined, has considerable strength when air dried and significant strength when wet.

Current The flow of water through a stream channel.

Dead blow hammer A hammer filled with lead shot or sand.

Deadman A log or concrete block buried in a streambank to anchor revetments.

Deposition The accumulation of soil particles on the channel bed, banks, and flood plain.

Discharge The volume of water passing through a channel during a given time, usually measured in cubic feet per second.

Dormant season The time of year when plants are not growing and deciduous plants shed their leaves.

Duration of flow Length of time a stream floods.

Erosion control fabric Woven or spun material made from natural or synthetic fibers and placed to prevent surface erosion.

Erosion The wearing away of the land by the natural forces of wind, water, or gravity.

Erosive (erodible) A soil whose particles are easily detached and entrained in a fluid, either air or water, passing over or through the soil. The most erodible soils tend to be silts and/or fine sands with little or no cohesion.

Failure Collapse or slippage of a large mass of streambank material.

Filter A layer of fabric, sand, gravel, or graded rock placed between the bank revetment or channel lining and soil to prevent the movement of fine grained sizes or to prevent revetment work from sinking into the soil.

Fines Silt and clay particles.

Flanking Streamflow between a structure and the bank that creates an area of scour.

Flow rate Volume of flow per unit of time; usually expressed as cubic feet per second.

Footer log A log placed below the expected scour depth of a stream. Foundation for a rootwad and boulders.

Gabion A wire mesh basket filled with rock that can be used in multiples as a structural unit.

Geotextile Any permeable textile used with foundation soil, rock, or earth as an integral part of a product, structure, or system usually to provide separation, reinforcement, filtration, or drainage.

Groin A structure built perpendicular to the shoreline to trap littoral drift and retard erosion.

Ground water Water contained in the voids of the saturated zone of geologic strata.

Headcutting The development and upstream movement of a vertical or near vertical change in bed slope, generally evident as falls or rapids. Headcuts are often an indication of major disturbances in a stream system or watershed.

Joint planting The insertion of live branch cuttings in openings or interstices of rocks, blocks, or other inert revetment units and into the underlying soil.

Littoral drift The movement of littoral drift either transport parallel (long shore transport) or perpendicular (on-shore transport) to the shoreline.

Littoral The sedimentary material of shorelines moved by waves and currents.

Littoral zone An indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

Live branch cuttings Living, freshly cut branches from woody shrub and tree species that readily propagate when embedded in soil.

Live cribwall A rectangular framework of logs or timbers filled with soil and containing live woody cuttings that are capable of rooting.

Live fascine Bound, elongated, cylindrical bundles of live branch cuttings that are placed in shallow trenches, partly covered with soil, and staked in place.

Live siltation construction Live branch cuttings that are placed in trenches at an angle from shoreline to trap sediment and protect them against wave action.

Live stake Live branch cuttings that are tamped or inserted into the earth to take root and produce vegetative growth.

Noncohesive soil Soil, such as sand, that lacks significant internal strength and has little resistance to erosion.

Piling (sheet) Strips or sheets of metal or other material connected with meshed or interlocking members to form an impermeable diaphragm or wall.

Piling A long, heavy timber, concrete, or metal support driven or jetted into the earth.

Piping The progressive removal of soil particles from a soil mass by percolating water, leading to the development of flow channels or tunnels.

Reach A section of a stream's length.

Reed clump A combination of root divisions from aquatic plants and natural geotextile fabric to protect shorelines from wave action.

Revetment (armoring) A facing of stone, interlocking pavers, or other armoring material shaped to conform to and protect streambanks or shorelines.

Riprap A layer, facing, or protective mound of rubble or stones randomly placed to prevent erosion, scour, or sloughing of a structure of embankment; also, the stone used for this purpose.

Rootwad A short length of tree trunk and root mass.

Scour Removal of underwater material by waves or currents, especially at the base or toe of a streambank or shoreline.

Sediment deposition The accumulation of sediment.

Sediment load The amount of sediment in transport.

Sediment Soil particles transported from their natural location by wind or water.

Seepage The movement of water through the ground, or water emerging on the face of a bank.

Slumping (sloughing) Shallow mass movement of soil as a result of gravity and seepage.

Stream-forming flow The discharge that determines a stream's geomorphic planform dimensions. Equivalent to the 1- to 3-year frequency flow event (see Bankfull discharge).

Streambank The side slopes within which streamflow is confined.

Streambed (bed) The bottom of a channel.

Streamflow The movement of water within a channel.

Submerged vanes Precast concrete or wooden elements placed in streambeds to deflect secondary currents away from the streambank.

Thalweg The deepest part of a stream channel where the fastest current is usually found.

Toe The break in slope at the foot of a bank where it meets the streambed.

Vegetated geogrid Live branch cuttings placed in layers with natural or synthetic geotextile fabric wrapped around each soil lift.

Vegetated structural revetments Porous revetments, such as riprap or interlocking pavers, into which live plants or cuttings can be placed.

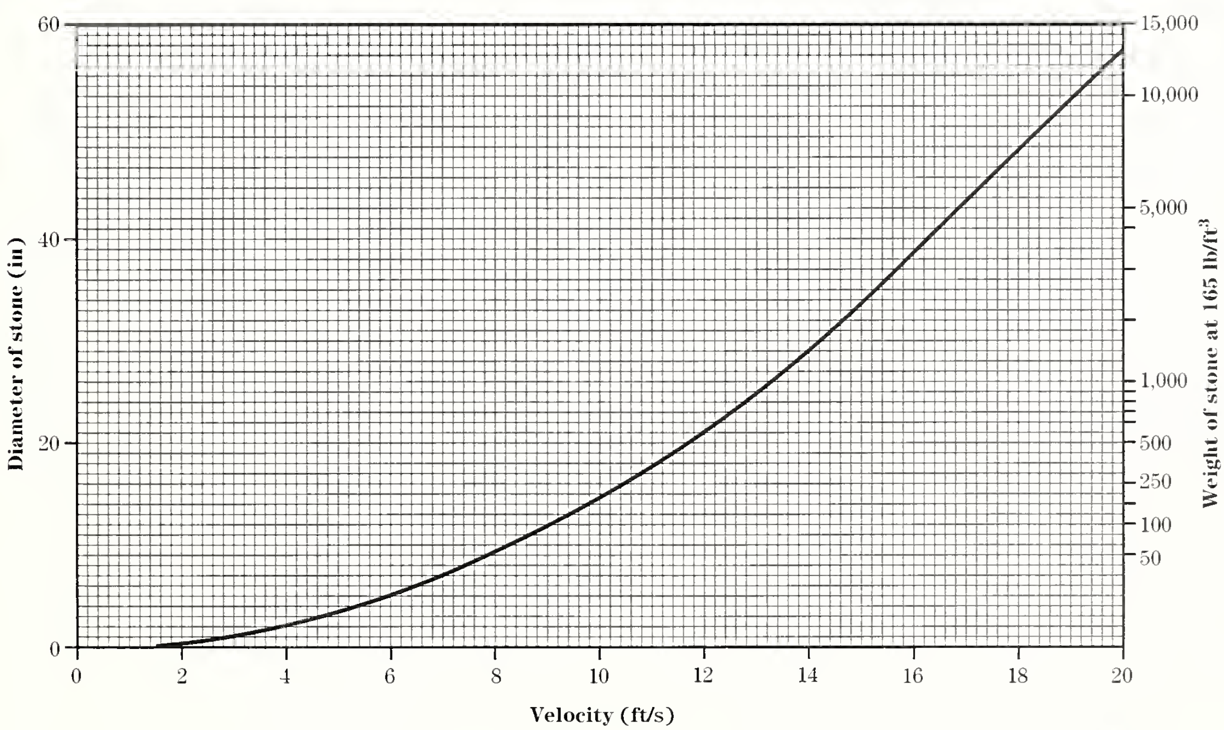
Vegetated structures A retaining structure in which live plants or cuttings have been integrated.

Appendix 16A Size Determination for Rock Riprap

Isbash Curve

The Isbash Curve, because of its widespread acceptance and ease of use, is a direct reprint from the previous chapter 16, Engineering Field Manual. The curve was developed from empirical data to determine a rock size for a given velocity. See figure 16A–1. The user can read the D_{100} rock size (100 percent of riprap $\leq$ this size) directly from the graph in terms of weight (pounds) or dimension (inches). Less experienced users should use this method for quick estimates or comparison with other methods before determining a final design.

Figure 16A–1 Rock size based on Isbash Curve



Based on Isbash Curve

Procedure
1. Determine the design velocity.
2. Use velocity and fig. 16A-1 (Isbash Curve) to determine basic rock size.
3. Basic rock size is the D_{100} size.

Figure 16A–2 Rock size based on Far West States (FWS)-Lane method

$D_s = \frac{3.5}{CK} \text{ w D S}$ $\quad D_s = D_{75}$ size rock in inches

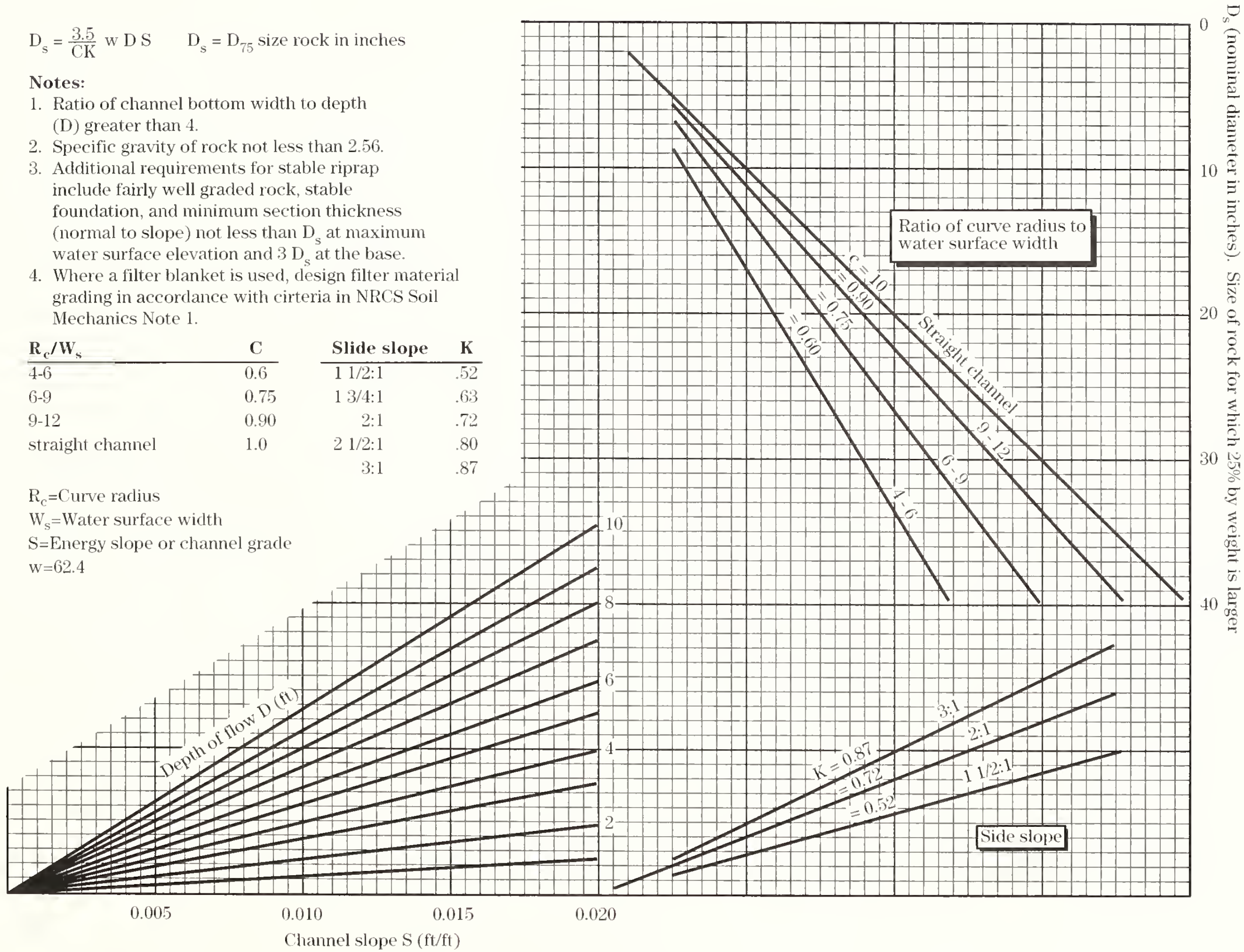
Notes:

1. Ratio of channel bottom width to depth (D) greater than 4.
2. Specific gravity of rock not less than 2.56.
3. Additional requirements for stable riprap include fairly well graded rock, stable foundation, and minimum section thickness (normal to slope) not less than D_s at maximum water surface elevation and 3 D_s at the base.
4. Where a filter blanket is used, design filter material grading in accordance with cirteria in NRCS Soil Mechanics Note 1.

R_c/W_s	C
4-6	0.6
6-9	0.75
9-12	0.90
straight channel	1.0

Slide slope	K
1 1/2:1	.52
1 3/4:1	.63
2:1	.72
2 1/2:1	.80
3:1	.87

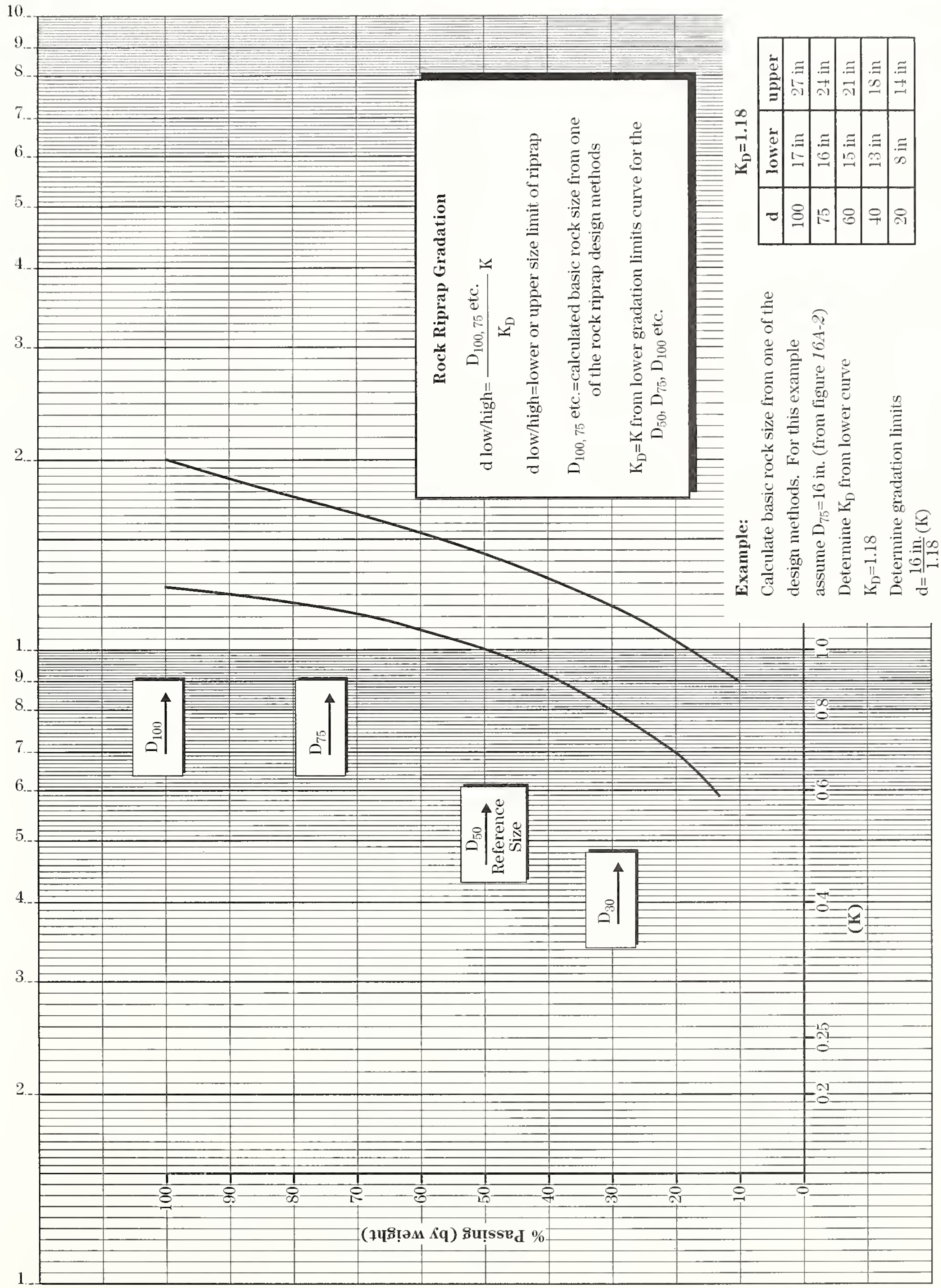
R_c=Curve radius
W_s=Water surface width
S=Energy slope or channel grade
w=62.4



Procedure

1. Determine the average channel grade or energy slope.
2. Enter fig. 16A-2 with energy slope, flow depth, and site physical characteristics to determine basic rock size.
3. Basic rock size is the D_{75} size.

Figure 16A–3 Gradation limits curve for determining suitable rock gradation



Rock Riprap Gradation

$$d\ low/high = \frac{D_{100,\,75}\ etc.}{K_D}\ K$$

d low/high=lower or upper size limit of riprap

$D_{100,\,75}$ etc.=calculated basic rock size from one of the rock riprap design methods

K_D=K from lower gradation limits curve for the D_{50}, D_{75}, D_{100} etc.

K_D=1.18

d	lower	upper
100	17 in	27 in
75	16 in	24 in
60	15 in	21 in
40	13 in	18 in
20	8 in	14 in

Example:

Calculate basic rock size from one of the design methods. For this example assume D_{75}=16 in. (from figure *16A-2*)

Determine K_D from lower curve

K_D=1.18

Determine gradation limits

$$d = \frac{16\ in.}{1.18}\ (K)$$

Appendix 16B Plants for Soil Bioengineering and Associated Systems

The information in appendix 16B is from the Natural Resources Conservation Service's data base for Soil Bioengineering Plant Materials (biotype). The plants are listed in alphabetical order by scientific name. Further subdivision of the listing should be considered to account for local conditions and identify species suitable only for soil bioengineering systems.

Table header definitions (in the order they occur on the tables):

Scientific name—Genus and species name of the plant.

Common name—Common name of the plant.

Region of occurrence—Region(s) of occurrence using the regions of distribution in PLANTS (Plant List of Attributes, Nomenclature, Taxonomy, and Symbols, 1994). Region code number or letter:

- 1 Northeast—ME, NH, VT, MA, CT, RI, WV, KY, NY, PA, NJ, MD, DE, VA, OH
- 2 Southeast—NC, SC, GA, FL, TN, AL, MS, LA, AR
- 3 North Central—MO, IA, MN, MI, WI, IL, IN
- 4 North Plains—ND, SD, MT (eastern) WY (eastern)
- 5 Central Plains—NE, KS, CO (eastern)
- 6 South Plains—TX, OK
- 7 Southwest—AZ, NM
- 8 Intermountain—NV, UT, CO (western)
- 9 Northwest—WA, OR, ID, MT (western) WY (western)
- 0 California—Ca
- A Alaska—AK
- C Caribbean—PR, VI, CZ, SQ
- H Hawaii—HI, AQ, GU, IQ, MQ, TQ, WQ, YQ

Commercial availability—Answers whether the plant is available from commercial plant vendors.

Plant type—Short description of the type of plant: tree, shrub, grass, forb, legume, etc.

Root type—Description of the root of the plant: tap, fibrous, suckering, etc.

Rooting ability from cutting—Subjective rating of cut stems of the plant to root without special hormone and/or environmental surroundings provided.

Growth rate—Subjective rating of the speed of growth of the plant: slow, medium, fast, etc.

Establishment speed—Subjective rating of the speed of establishment of the plant.

Spread potential—Subjective rating of the potential for the plant to spread: low, good, etc.

Plant materials—The type of vegetation plant parts that can be used to establish a new colony of the species.

Notes—Other important or interesting characteristics about the plant.

Soil preference—Indication of the type of soil the plant prefers: sand, loam, clay, etc.

pH preference—Lists the pH preference(s) of the plant.

Drought tolerance—Subjective rating of the ability of the plant to survive dry soil conditions.

Shade tolerance—Subjective rating of the ability of the plant to tolerate shaded sites.

Deposition tolerance—Subjective rating of the ability of the plant to tolerate deposition of soil or organic debris around or over the roots and stems.

Flood tolerance—Selective rating of the ability of the plant to tolerate flooding events.

Flood season—Time of the year that the plant can tolerate flooding events.

Minimum water depth—The minimum water depth required by the plant for optimal growth.

Maximum water depth—The maximum water depth the plant can tolerate and not succumb to drowning.

Wetland indicator—A national indicator from National List of Plant Species that Occur in Wetlands: 1988 National Summary.

Table 16B–1 Woody plants for soil bioengineering and associated systems

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Acer circinatum	vine maple	9,0	yes, but in limited quantities	shrub to small tree	fibrous, rooting at nodes	fair to good	slow	slow	good	plants	Branches often touch& root at ground level. Often occurs with conifer overstory. Occurs British Columbia to CA.
Acer glabrum	dwarf maple	4,5,7, 8,9,0, A	yes	small tree		poor				plants	usually dioecious, grows in poor soils.
Acer negundo	boxelder	1,2,3, 4,5,6, 7,8,9, 0	yes	small to medium tree	fibrous, moderately deep, spreading, suckering	poor	fast	fast	fair	plants, rooted cuttings	Use in sun & part shade. Survived deep flooding for one season in Pacific NW.
Acer rubrum	red maple	1,2,3, 6	yes	medium tree	shallow	poor	fast when young	medium	good	plants	Not tolerant of high pH sites. Occurs on and prefers sites with a high water table and/or an annual flooding event.
Acer saccharinum	silver maple	1,2,3, 4,5,6, 8	yes	medium tree	shallow, fibrous	poor	fast when young	medium	fair	plants	Plants occur mostly east of the 95th parallel. Survived 2 years of flooding in MS.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Alnus pacifica	pacific alder			tree		poor	most alders are fast			plants	A species for forested wetland sites in the Pacific northwest. Plant on 10- to 12-foot spacing.
Alnus rubra	red alder	9,0,A	yes	medium tree	shallow, spreading, suckering	poor to fair	fast	fast	good	plants	Usually grows west of the Cascade Mtns, within 125 milesof the ocean & below 2,400 feet elevation. A nitrogen source. Short lived species. May be seedable. Susceptible to caterpillars.
Alnus serrulata	smooth alder	1,2,3, 5,6	yes	large shrub	shallow, spreading	poor	slow	medium	fair	plants	Thicket forming. Survived 2 years of flooding in MS. Roots have relation with nitrogen-fixing actinomycetes, susceptible to ice damage, needs full sun.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Alnus viridis ssp.sinuata	sitka alder	9,0,A	yes, but very limited quan-tities	shrub to small tree	shallow	poor	rapid first year, moderate thereafter	medium	fair to good	plants	A nitrogen source. Occurs AK to CA.
Amelanchier alnifolia var cusickii	cusick's serviceberry	9	yes	shrub		poor	medium	medium	medium	plants	Usually seed propagated. Occurs in eastern WA, northern ID, & eastern OR. A different variety is Pacific serviceberry A. alnifolia var semiintegrifolia. Host to several insect & disease pests.
Amelanchier utahensis	utah serviceberry	9		small to large shrub						plants	Occurs in southeast OR, south ID, NV, & UT.
Amorpha fruitcosa	false indigo	1,2,3, 4,5,6, 7,8,0	yes	shrub		poor	medium	fast	poor	plants, seed	Supposedly root suckers. Has been seeded directly on roadside cut and fill sites in MD.
Aronia arbutifolia	red chokeberry	1,2,3, 6	yes	shrub		poor	fast	fast		plants, seed	Rhizomatous. May produce fruit in second year.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Asimina triloba	pawpaw	1,2,3, 5,6	yes	small tree	tap and root suckers	poor to fair	fast		poor	root cuttings, plants	Does produce thickets where native & can be propagated by layering & root cuttings. Occurs NY to FL & TX.
Baccharis glutinosa	seepwillow	6,7,8, 0	yes	medium shrub	deep & wide-spreading, fibrous	good				plants	Thicket forming.
Baccharis halimifolia	eastern baccharis	1,2,6	yes	medium shrub	fibrous	good	fair	fast	fair	fascines, cuttings, plants,	Resistant to salt spray; unisexual plants. Occurs MA to FL & TX.
Baccharis pilularis	coyotebush	9,0		medium evergreen shrub	fibrous	good			fair	fascines, stakes, brush mats, layering, cuttings	Pioneer in gullies, many forms prostrate & spreading. May be seedable. Colony-forming to 1 foot high in CA coastal bluffs.
Baccharis salicifolia	water wally	6,7,8, 0		medium evergreen shrub	fibrous, deep, wide-spreading	good			fair	fascines, brush mats, stakes, layering, cuttings	Was B. glutinosa. Thicket forming, unisexual plants.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Celtis laevigata	sugarberry	1,2,3, 5,6,7, 9,0	yes	medium tree	relatively shallow	poor	medium	slow	low	plants	Very resistant to witches-broom. Occurs FL, west to TX & southern IN. Also in Mexico. Leaf fall allelopathic.
Celtis occidentalis	hackberry	1,2,3, 4,5,6, 8	yes	medium tree	medium to deep fibrous	poor	medium to fast	slow	low	plants	Survived 2 years of flooding in MS. Not tolerate more than a few days inundation in a MO trial. Susceptible to witches-broom. Occurs Quebec to NC & AL.
Cephalanthus occidentalis	buttonbush	1,2,3, 5,6,7, 8,0	yes	large shrub		fair to good	slow	medium	poor	brush mats, layering, plants	Survived 3 years of flooding in MS. Will grow in sun or shade.
Cercis canadensis	redbud	1,2,3, 5,6,7, 8	yes	small tree	tap	poor	slow	slow	poor	plants	Juvenile wood & roots will root.
Chilopsis linearis	desert willow	6,7,8, 0	yes	shrub	fibrous		medium	medium	low	plants	Occurs TX to southern CA & into Mexico. 'Barranco,' 'Hope,' & 'Regal' cultivars were releasedin New Mexico.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Chionanthus virginicus	fringetree	1,2,3, 6	yes	small tree		poor	slow		poor	plants	Susceptible to severe browsing & scale. Occurs PA to FL & west to TX.
Clematis ligusticifolia	western clematis	1,2,4, 5,6,7, 8,9,0	yes	vine	shallow & fibrous	poor	fast	fast	good	plants	Produces new plants from layering in sandy soils at 7- to 8-inch precip & 1,000-foot elevation.
Clethera alnifolia	sweet pepperbush	1,2,6	yes	shrub		poor	slow			plants	Has rhizomes; salt tolerant on coastal sites. Occurs ME to FL.
Cornus amomum	silky dogwood	1,2,3, 4,5,6	yes	small shrub	shallow, fibrous	fair	fast	medium	poor	fascines, stakes, brush mats, layering, cuttings, plants	Pith brown, tolerates partial shade. 'Indigo' cultivar was released by MI PMC.
Cornus drummondii	roughleaf dogwood	1,2,3, 4,5,6	yes	large shrub	root suckering, spreading	fair			fair	fascines, stakes, layering, brush mats, cuttings, plants	Root suckers too. Pith usually brown. Occurs Saskatchewan to KS & NE, south to MS, LA, & TX.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Cornus florida	flowering dogwood	1,2,3, 5,6	yes	small tree	shallow, fibrous	poor	fair	fair	poor	plants	Hard to transplant as bare root; coppices freely. Not tolerant of flooding in TN Valley trial.
Cornus foemina	stiff dogwood	1,2,3, 4,5,6		medium shrub		fair	fast			fascines, plants	Formerly C. racemosa Occurs VA to FL & west to TX. Pith white.
Cornus racemosa	gray dogwood	1,2,3, 4,5,6	yes	medium to small shrub	shallow, fibrous	fair	medium		fair	fascines, stakes, brush mats, layering, cuttings, plants	Forms dense thickets. Pith usually brown, tolerates city smoke. Occurs ME & MN to NC & OK.
Cornus rugosa	roundleaf dogwood	1,3		medium to small shrub	shallow, fibrous	fair to good				fascines, cuttings, plants	Pith white. Use in combination with species with root_abil = good to excellent. Occurs Nova Scotia to VA & ND.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Cornus sericea ssp sericea	red-osier dogwood	1,3,4, 5,7,8, 9,0,A	yes	medium shrub	shallow	good	fast	medium	fair	fascines, stakes, brush mats, layering, cuttings, plants	Forms thickets by rootstocks & rooting of branches. Survived 6 years of flooding in MS. Pith white, tolerates partial shade. Formerly C. stolonifera. 'Ruby' cultivar was released by NY PMC.
Cornus stricta	swamp dogwood			shrub		poor				plants	May be same as C. foemina.
Crataegus douglasii	douglas hawthorn	3,8,9, 0,A	yes	small tree	tap to fibrous	poor to fair	slow		poor	cuttings, plants	Forms dense thickets on moist sites. Grown from seed or grafted. Occurs British Columbia to CA & MN.
Crataegus mollis	downy hawthorn	1,2,3, 4,5,6	yes	tree	tap	poor to fair				plants	Occurs Ontario & MN to AL, AR & MS. 'Homestead' cultivar was released by ND PMC.
Cyrilla racemiflora	titi	1,2,6, C		small tree		poor				plants	Semievergreen, a good honey plant. Occurs VA to FL & on to South America. Prefers organic sites.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Diospyros virginiana	persimmon	1,2,3, 5,6	yes	medium tree	tap	poor	slow	fair	poor	plants	Forms dense thickets on dry sites. Stoloniferous & tap rooted. Occurs CT toFL & TX.
Elaeagnus commutata	silverberry	1,3,4, 8,9,A	yes	small tree	shallow, fibrous	poor to fair	fast	fast	fair	plants	Grows well in limestone & alkaline soils.
Forestiera acuminata	swamp privet	1,2,3, 6	yes	large shrub to small tree		fair	slow		poor	plants	Thicket forming. Survived 3 years of flooding in MS.
Fraxinus caroliniana	carolina ash	1,2,6		large tree	fibrous	poor	fast	fast		plants	Easily transplanted. Occurs in swamps VA to TX.
Fraxinus latifolia	oregon ash	9,0	yes	medium tree	moderately shallow, fibrous	poor	fast when young	medium	fair	plants	May be grown from seed but usually grafted. Usually occurs west of the Cascade Mtns.
Fraxinus pennsylvanica	green ash	1,2,3, 4,5,6, 8,9	yes	medium tree	shallow, fibrous	poor	fast	fast	good	plants	Survived 3 years of flooding in MS. 'Cardan' cultivar was released by ND PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Gleditsia triacanthos	honeylocust	1,2,3, 4,5,6, 7,8,9	yes	medium tree	deep & wide-spread	poor to fair	fast	fast	medium	plants	Survived deep flooding for 100 days 3 consecutive years. Has been used in reg_occ 7,8,9. Native ecotypes have thorns!
Hibiscus aculeatus	hibiscus	2,6	yes	shrub		poor				plants	
Hibiscus laevis	halberd-leaf marshmallow		yes	shrub		poor				plants	Was H. militaris.
Hibiscus moscheutos	common rose mallow	1,2,3, 5,6,7, 0	yes	shrub		poor				plants	
Hibiscus moscheutos ssp.lasiocarpos	hibiscus		yes	shrub		poor				plants	
Holodiscus discolor	oceanspray	9,0	yes, from contract growers.	shrub		poor to fair	medium to rapid	fast	poor	plants	Often pioneers on burned areas. Occurs from British Columbia to CA to ID. Usually grown from seed or cuttings.
Ilex coriacea	sweet gallberry	1,2,6, C	yes	small to large shrub		poor				plants	Evergreen.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Ilex decidua	possomhaw	1,2,3, 5,6	yes	large shrub to small tree		poor	slow			plants	Survived 3 years of flooding in MS.
Ilex glabra	bitter gallberry	1,2,6	yes	small shrub		poor	slow			plants	Evergreen, sprouts after fire. Stoloniferous! Occurs eastern US & Canada.
Ilex opaca	american holly	1,2,3, 6	yes	small tree	tap root & prolific laterals	poor	slow	medium	poor	plants	Easy to transplant when young.
Ilex verticillata	winterberry	1,2,3, 6	yes	small to large shrub		poor	slow			plants	Prefers seasonally flooded sites. Plants dioecious.
Ilex vomitoria	yaupon	1,2,6	yes	large shrub		poor				plants	Root suckers.
Juglans nigra	black walnut	1,2,3, 4,5,6	yes	medium tree	tap & deep & wide-spread laterals	poor	fair	fair	poor	plants	Though drought tolerant, will not grow on poor or dry soil sites. Not tolerate flooding in TN Valley trial.
Juniperus virginiana	eastern redcedar	1,2,3, 4,5,6	yes	large tree	tap & dense fibrous laterals	poor	slow	medium	good	plants	Not tolerate flooding in TN Valley trial.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Leucothoe axillaris	leucothoe	1,2	yes	small to large shrub		poor	slow			plants	Evergreen.
Lindera benzoin	spicebush	1,2,3, 5,6	yes	shrub		poor	slow			plants	Prefers acid soils. Dioecious.
Liquidambar styraciflua	sweetgum	1,2,3, 6	yes	large tree	tap to fibrous	poor	slow		fair	plants	A species for forested wetland sites.
Liriodendron tulipifera	tulip poplar	1,2,3, 5,6	yes	large tree	deep & wide-spreading	poor	fast	fast		plants	Hard to transplant.
Lonicera involucrata	black twinberry	3,7,8, 9,0,A	yes	small to large shrub	fibrous & shallow	good	fast	fast	poor to fair	fascines, stakes, cuttings, plants	
Lyonia lucida	fetterbush	1,2		small to large shrub		poor				plants	Evergreen.
Magnolia virginiana	sweetbay	1,2,6	yes	small tree		poor	slow			plants	Occurs in swamps from MA to FL and west to east TX.
Myrica cerifera	southern waxmyrtle	1,2,6, c	yes	small shrub	fibrous	poor	medium	slow	slow	plants	Evergreen. Occurs east TX & OK, east to FL & north to NJ.
Nyssa aquatica	swamp tupelo	1,2,3, 6	yes	large tree	shallow, fibrous	poor		slow		plants	Trees from the wild do not transplant well.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Nyssa ogeeche	ogeeche lime	2		large shrub to small tree	sparse, fibrous	poor	slow	medium	poor	plants	Largest fruit of all Nyssa. Vegetative reproduction not noted. Only grows close to perennial wetland sites.
Nyssa sylvatica	blackgum	1,2,3, 6	yes	tall tree	sparse, fibrous, very long, descending	poor	medium	slow	fair	plants	A species for forested wetland sites. Difficult to transplant but plant in sun or shade on 10- to 12-foot spacing.
Ostrya virginiana	hophorn-beam	1,2,3, 4,5,6	yes	small tree		poor	slow	slow		plants	Difficult to transplant. Tolerated flooding for up to 30 days during 1 growing season.
Persea borbonia	redbay	1,2,6	yes	small to large evergreen tree		poor	slow	slow		plants	
Philadelphus lewesii	lewis mockorange	9,0	yes	large shrub	fibrous	poor	fast	medium to fast	medium	plants	Usually grown from seed.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Physocarpus capitatus	pacific ninebark	8,9,0, A	yes	large shrub	fibrous	good				fascines, brush mats, layering, cuttings, plants	Usually occurs west of the Cascade Mtns.
Physocarpus malvaceus	mallow ninebark	8,9	yes	small shrub	shallow but with rhizomes	fair				cuttings, plants	Propagated by seed or cuttings. Usually occurs east of the Cascade Mtns.
Physocarpus opulifolius	common ninebark	1,2,3, 4,5,6, 8,9	yes	medium shrub	shallow, lateral	fair	slow	slow	poor	fascines, brush mats, layering, cuttings, plants	Use in combination with other species with rooting ability good to excellent.
Pinus taeda	loblolly pine	1,2,3, 6	yes	medium tree	short tap changes to shallow spreading laterals	poor	fast	fast	poor	plants	
Planera aquatica	water elm	1,2,3, 5,6		small tree		poor	fairly fast			plants	Occurs KY to FL. west to IL & TX.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Platanus occidentalis	sycamore	1,2,3, 5,6	yes	large tree	fibrous, wide-spreading	poor	fast	fast	medium	plants	A species for forested wetland sites. Tolerates city smoke & alkali sites. Plant on 10- to12-foot spacing. Transplants well.
Platanus racemosa	California sycamore	0		tall tree						plants	A species for forested wetlands sites in CA.
Populus angustifolia	narrowleaf cottonwood	4,5,6, 7,8,9, 0		large tree	shallow	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Under development in ID for riparian sites.
Populus balsamifera	balsam poplar	1,2,3, 4,5,8, 9,O,A	yes	tall tree	deep, fibrous	v good	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Populus deltoides	eastern cottonwood	1,2,3, 4,5,6, 7,8,9	yes	tall tree	shallow, fibrous, suckering	v good	fast	fast	poor	fascines, stakes, poles, brush mats, layering, cuttings, root suckers, plants	Short lived. Endures heat & sunny sites. Survived over 1 year of flooding in MS. Hybridizes with several other poplars. Plant roots may be invasive. May be sensitive to aluminum in the soil.
Populus fremontii	fremont cottonwood	6,7,8, 0		tree	shallow, fibrous	v good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Tolerates saline soils. Dirty tree.
Populus tremuloides	quaking aspen	1,2,3, 4,5,7, 8,9,0, A	yes	medium tree	shallow, profuse suckers, vigorous underground runners	poor to fair	fast	fast	fair	layering, root cuttings, plants	Short lived. A pioneer species on sunny sites. Normal propagation is by root cuttings. Not tolerant of more than a few days inundation in a New England trial. Use rooted plant materials.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Populus trichocarpa	black cottonwood	4,7,8, 9,0,A	yes	large tree	deep & wide-spread, fibrous	v good	fast	fast	good	fascines, stakes, poles, brush mats, layering, cuttings, plants	A species for forested wetland sites. Was P. trichophora. Usually grown from cuttings. Under development in ID for riparian sites. Plant on 10- to 12-foot spacing. May be P. balsimifera
Prunus angustifolia	wild plum	1,2,3, 5,6	yes	small shrub	fibrous, spreading, suckering	poor	medium	fast	good	plants, root cuttings	Thicket forming. 'Rainbow' cultivar released by Knox City, TX, PMC.
Prunus virginiana	common chokecherry	1,2,3, 4,5,6, 7,8,9, 0,A	yes	large shrub	shallow, suckering	poor	medium	medium	fair	plants	A species for forested wetland sites. Has hydrocyanic acid in most parts, especially the seeds. Usually grown from seed. Thicket forming. Plant on 5- to 8-foot spacing. Reportedly poisonous to cattle.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Quercus alba	white oak	1,2,3, 5,6	yes	large tree	tap to deep, well-developed fibrous	poor	slow	slow	slow	plants	Did not survive more than a few days flooding in a trial in New England. Difficult to transplant larger specimens.
Quercus bicolor	swamp white oak	1,2,3, 5,6	yes	medium tree	somewhat shallow	poor	fast	medium	fair	plants	Survived 2 years of flooding in MS.
Quercus garryana	oregon white oak	9,0	yes	shrub to large tree	deep tap & well-developed laterals	poor	slow	slow	fair	plants	Usually grows west of the Cascade Mtns, in the Columbia River Gorge to the Dalles & to Yakima, WA. Propagated from seed sown in fall.
Quercus laurifolia	swamp laurel oak	1,2,6		tree	tap	poor	fast	fast		plants	Often used as a street tree in the southeast US.
Quercus lyrata	overcup oak	1,2,3, 6	yes	medium tree	tap deteriorates to dense shallow laterals	poor	slow	slow	slow	plants	Often worthless as a lumber species.
Quercus macrocarpa	bur oak	1,2,3, 4,5,6, 9	yes	large tree	deep tap & well-developed laterals	poor	medium	fast	poor	plants	Survived 2 years of flooding in MS. 'Boomer' cultivar released by TX PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Quercus michauxii	swamp chestnut oak	1,2,3, 6		medium tree	tap & deep laterals	poor	fair	fair	poor	plants	
Quercus nigra	water oak	1,2,3, 6		medium tree	shallow & spreading	poor	fast on good sites	slow	poor	plants	Easily transplanted.
Quercus pagoda	cherrybark oak			tree		poor				plants	
Quercus palustris	pin oak	1,2,3, 5,6	yes	large tree	well-developed fibrous laterals after taproot disinte-grates	poor	fast	fast	fair	plants	A species for forested wetland sites. Survived 2 years of flooding in MS. Plant on 10- to 12-foot spacing.
Quercus phellos	willow oak	1,2,3, 6	yes	medium to large tree	shallow, fibrous	poor	fast	medium	fair	plants	Easily transplanted.
Quercus shumardii	shumard oak	1,2,3, 5,6	yes	large tree	shallow	poor	medium	slow	low	plants	
Rhododendron atlanticum	coast azalea	1,2		small shrub		poor	fast		good by stolons	plants	Mat forming from suckers & stolons. Occurs from DE to SC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Rhododendron viscosum	swamp azalea	1,2		shrub		poor	slow			plants	Has stoloniferous forms. Occurs from ME to SC. Highly susceptible to insects & diseases.
Rhus copallina	flameleaf sumac	1,2,3, 4,5,6	yes	medium shrub	fibrous, suckering	poor to fair	fast	fast	fair	root cuttings, root suckers, plants	Thicket forming.
Rhus glabra	smooth sumac	1,2,3, 4,5,6, 7,8,9	yes	large shrub	fibrous, suckering	poor to fair	fast	fast	fair to good	root cuttings, root suckers, plants	Thicket forming.
Robinia pseudoacacia	black locust	1,2,3, 4,5,6, 7,8,9, 0	yes	medium tree	shallow	poor	medium to fast	fast	good	root cuttings, plants	Normal propagation is by root cuttings or seed. Not tolerant of flooding in TN Valley trial. Escaped in regions 5,7,8,9,0. Reported toxic to livestock.
Rosa gymnocarpa	baldhip rose	9,0		shrub		fair to good				cuttings, plants	A browsed species.
Rosa nutkana	nootka rose	7,8,9, 0,A		shrub		fair to good				cuttings, plants	A browsed species.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Rosa palustris	swamp rose	1,2,3, 5		small shrub	shallow	good				fascines, plants	
Rosa virginiana	virginia rose	1,2,3	yes	small shrub	rhizomatous & fibrous	good	fair	fast	fair	plants	
Rosa woodsii	woods rose	3,4,5, 6,7,8, 9,0,A		shrub		fair to good				cuttings, plants	A browsed species.
Rubus allegheniensis	allegheny blackberry	1,2,3, 5,6,0		small shrub	fibrous	good				plants	Normal propagation is by root cuttings.
Rubus idaeus ssp. strigosus	red raspberry	1,2,3, 4,5,6, 7,8,9, A		small shrub	fibrous	good				plants	Was R. strigosus. Normal propagation is by root cuttings.
Rubus spectabilis	salmonberry	9,0,A		small shrub	fibrous	good				plants	Normal propagation is by root cuttings. Use in combination with other species. Rooting ability is good to excellent.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix X cottetii	dwarf willow	not native	yes	small shrub	shallow	v good	medium	fast	poor	fascines, stakes, brush mats, layering, cuttings, plants	Not a native species. Plant plants on 2' to 6' spacing. 'Bankers' cultivar released by Kentucky PMC.
Salix amygdaloides	peachleaf willow	1,2,3, 4,5,6, 7,8,9	yes	large shrub to small tree	shallow to deep	v good	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Often roots only at callus cut. May be short-lived. Under development in ID for riparian sites. Not tolerant of shade. Hybridized with several other willow species.
Salix bebbiana	bebb's willow	1,3,4, 5,7,8, 9,A		small shrub to large tree	fibrous					cuttings, plants	Does not form suckers. Usually east of the Cascade Mtns & in ID & MT.
Salix bonplandiana	pussy willow	7	yes	medium shrub to large tree	fibrous	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Eaten by livestock when young.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Salix boothii	booth willow	8,9		shrub							Under development in Idaho for riparian sites.
Salix discolor	pussy willow	1,2,3, 4,9	yes	large shrub	shallow, fibrous, spreading	v good	rapid			fascines, stakes, poles, layering, cuttings, plants	Use on sunny to partial shade sites.
Salix drummondiana	drummond's willow	7,8,9, 0	yes	shrub		good				fascines, cuttings, plants	Usually east of the Cascade Mtns. Under development in ID for riparian sites. 'Curlew' cultivar released by WA PMC.
Salix eriocephala	erect willow	7,8,9, 0	yes	large shrub	fibrous	v good		fast		fascines, stakes, poles, layering, cuttings, plants	A botanic discrepancy in the name, it may be S. ligulifolia! 'Placer' cultivar released by OR PMC.
Salix exigua	coyote willow	1,2,3, 4,5,6, 7,8,9, 0,A	yes	medium shrub	shallow, suckering, rhizomat-ous	good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Relished by livestock. Under development in ID for riparian sites. 'Silvar' cultivar released by WA PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix geyeriana	geyer's willow	7,8,9, 0		small to large shrub						cuttings, plants	Occurs east of the Cascade Mtns at higher elevations. Relished by livestock. Under development in ID for riparian sites.
Salix gooddingii	goodding willow	6,7,8, 0		small shrub to large tree	shallow to deep	good to excel	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Not tolerate alkaline sites. Some say this is western black willow.
Salix hookeriana	hooker willow	9,0	yes	large shrub to small tree	fibrous, dense	v good	rapid when young, medium there-after	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	May have salt tolerance. Can compete well with grasses. 'Clatsop' cultivar was released by OR PMC.
Salix humilis	prairie willow	1,2,3, 4,5,6		medium shrub	fibrous, spreading	good		medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Thicket forming.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix interior	sandbar willow	1,3,4, 5,7,8, 9,A	yes	large shrub	shallow to deep	exce	medium	medium	fair	fascines, stakes, poles, brush mats, layering, cuttings, plants	Thicket forming. This species has been changed to S. exigua. Use in combination with species with rooting ability good to excellent.
Salix lasiolepis	arroyo willow	6,7,8, 9,0	yes	tall shrub to small tree	fibrous	v good	rapid when young, medium thereafter	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Roots only on lower 1/3 of cutting or at callus. 'Rogue' cultivar released by OR PMC.
Salix lemmonii	lemmon's willow	8,9,0	yes	medium shrub	fibrous	v good		fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Occurs at high elevations, east of the Cascade Mtns. Under development in ID for riparian sites. 'Palouse' cultivar released by WA PMC.
Salix lucida	shining willow	1,3,4, 5,7,8, 9,0		medium to tall shrub	fibrous, spreading	v good	rapid			fascines, stakes, poles, brush mats, layering, cuttings, plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix lucida ssp. lasiandra	pacific willow	4,7,8, 9,0,A	yes	large shrub to small tree	fibrous	v good	medium to slow	medium to slow		fascines, stakes, poles, brush mats, layering, cuttings, plants	A species for forested wetlands sites. There are several subspecies of S. lucida. Under development in ID for riparian sites. Susceptible to several diseases and insects. Plant on 10- to 12-foot spacing. 'Nehalem' cultivar released by OR PMC.
Salix lutea	yellow willow	1,4,5, 7,8,9, 0		medium to tall shrub	fibrous	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Usually browsed by livestock. Under development in ID for riparian sites.
Salix nigra	black willow	1,2,3, 5,6,7, 8	yes	small to large tree	dense, shallow, sprouts readily	good to excel	fast	fast	good	fascines, stakes, poles, brush mats, layering, cuttings, root cuttings, plants	May be short lived. Survived 3 years of flooding in MS. Needs full sun. Susceptible to several diseases & insects.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Salix pentandra	laurel willow	not native	yes	large shrub to small tree	fibrous, spreading	good	fast	medium	poor	fascines, stakes, poles, brush mats, layering, cuttings, plants	From Europe, sparingly escaped in the East. Insects may defoliate it regularly.
Salix purpurea	purpleosier willow	1,2,3, 5	yes	medium tree	shallow	excel	fast	fast	poor	fascines, stakes, poles, brush mats, layering, cuttings, plants	Tolerates partial shade. 'Streamco' cultivar released by NY PMC.
Salix scouleriana	scouler's willow	4,7,8, 9,0,A		large shrub to small tree	shallow	v good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Pioneers on burned sites. Occurs on both sides of the Cascade Mtns in low to high eleva-tions. Often roots only at callus.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix sitchensis	sitka willow	9,0,A	yes	very large shrub		v good	rapid when young, medium thereafter	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Occurs on both sides of the Cascade Mtns. Vigorous shoots branch freely; lends itself to bioengineering uses; excellent survival in trials. 'Plumas' cultivar released by OR PMC.
Sambucus canadensis	american elder	1,2,3, 4,5,6, 8,9	yes	medium shrub	fibrous & stoloniferous	good	fast	fast	poor	fascines, cuttings, plants	Softwood cuttings root root easily in spring or summer. Pith white.
Sambucus cerulea	blue elderberry	6,7,8, 9,0	yes	large shrub	fibrous	poor	v fast	v fast	poor	plants	
Sambucus cerulea ssp. mexicana	mexican elder	6,7,8, 0,H		large shrub		good				fascines, plants	Was S. mexicana. Evergreen. Softwood cuttings root easily in spring or summer.
Sambucus racemosa	red elderberry	1,2,3, 4,7,8, 9,0,A	yes	medium shrub		good	medium	slow		fascines, brush mats, layering, cuttings, plants	Softwood cuttings root easily in spring or summer. Pith brown. This may be S. callicarpa.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Sambucus racemosa ssp. pubens	red elder	1,2,3, 4,9,A		medium shrub	deep laterals	fair to good				fascines, plants	Occurs west of the Cascade Mtns, usually within 10 miles of the ocean & on the coastal bays & estuaries. Soft-wood cuttings root easily in spring or summer. Pith brown. Use in com-bination with species with rooting ability good to excellent.
Spiraea alba	meadow-sweet spirea	1,2,3, 4	yes	short dense tree	dense shallow, lateral	fair to good		medium		plants	Propagation by leafy softwood cuttings in mid-summer under mist.
Spiraea betulifolia	shinyleaf spirea	1,2,4, 9		shrub						plants	Usually grown from seed. Occurs east of the Cascade Mtns at medium to high elevations.
Spiraea douglasii	douglas spirea	2,3,9, 0	yes	small dense shrub	fibrous, suckering	good	rapid	fast	excellent	fascines, brush mats, layering, cuttings, division of suckers, plants	Resists fire & pro-lific sprouter (forms thickets). Propaga-tion by leafy soft-wood cuttings in midsummer under mist. 'Bashaw' cul-tivar released by WA PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Spiraea tomentosa	hardhack spirea	1,2,3, 5		small shrub	dense, shallow	poor to fair				plants	Propagation by leafy softwood cuttings in mid-summer under mist. A weed in New England pastures. Use rooted materials.
Styrax japonica	Japanese snowbell	1,2,3, 5,6	yes	large shrub		poor				plants	
Symphoricarpos albus	snowberry	1,3,4, 5,7,8, 9,0,A	yes	small shrub, dense colony forming	shallow, fibrous, freely suckering	good	rapid	slow	fair	fascines, brush mats, layering, cuttings, plants	Plant in sun to part shade, especially on wet sites.
Taxodium distichum	baldcypress	1,2,3, 5,6	yes	medium tree	tap with laterals for knees for aeration	poor	medium	fast	poor	plants	Plant on 10- to 12-foot spacing. Toler-ates upland sites in region 6 with 32" rainfall.
Tsuga canadensis	eastern hemlock	1,2,3	yes	large tree	shallow fibrous	poor	slow	slow	low	plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Ulmus americana	american elm	1,2,3, 4,5,6, 8	yes	large tree	tap on dry sites to shallow fibrous on moist sites	poor	medium	medium	poor	plants	A species for forested wetland sites. Survived near 2 years of flooding in MS. Plant on 10- to 12-foot spacing; tolerates full shade.
Viburnum dentatum	arrowwood	1,2,3, 6	yes	medium to tall shrub	shallow, fibrous	good	fast	slow		layering, cuttings, plants	Thicket forming; tolerates city smoke. Use rooted plant materials.
Viburnum lantanoides	hubblebush viburnam	1,2,3		medium shrub	shallow, fibrous	good				fascines, stakes, brush mats, layering, cuttings, plants	Was V. alnifolium. Thicket forming. Branch tips root at soil.
Viburnum lentago	nannyberry	1,2,3, 4,5,9	yes	large shrub	shallow	fair to good	fast	fast		fascines, cuttings, stakes, plants	Thicket forming; tolerates city smoke. Tolerates full shade. Older branches often root when they touch soil. Use in combination with species with rooting ability good to excellent.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

cientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Viburnum nudum	swamp haw	1,2,6		large shrub		poor				plants	D. Wymann says it is more adapted to the South than V. cassinoides.
Viburnum trilobum	american cranberry-bush	1,3,4, 5,9	yes	medium shrub		poor	medium	slow		layering, plants	Use rooted plant materials. Fruits are edible.

Table 16B–2 Woody plants with fair to good or better rooting ability from unrooted cuttings

Scientific name	Common name	Scientific name	Common mame
Acer circinatum	vine maple	*Salix bonplandiana*	pussy willow
Baccharis glutinosa	seepwillow	*Salix discolor*	pussy willow
Baccharis halimifolia	eastern baccharis	*Salix drummondiana*	drummond's willow
Baccharis pilularis	coyotebush	*Salix eriocephala*	erect willow
Baccharis salicifolia	water wally	*Salix exigua*	coyote willow
Baccharis viminea	mulefat baccharis	*Salix gooddingii*	goodding willow
Cephalanthus occidentalis	buttonbush	*Salix hookeriana*	hooker willow
Cornus amomum	silky dogwood	*Salix humilis*	prairie willow
Cornus drummondii	roughleaf dogwood	*Salix interior*	sandbar willow
Cornus foemina	stiff dogwood	*Salix lasiolepis*	arroyo willow
Cornus racemosa	gray dogwood	*Salix lemmonii*	lemmon's willow
Cornus rugosa	roundleaf dogwood	*Salix lucida*	shining willow
Cornus sericea ssp sericea	red-osier dogwood	*Salix lucida ssp. lasiandra*	pacific willow
Lonicera involucrata	black twinberry	*Salix lutea*	yellow willow
Physocarpus capitatus	pacific ninebark	*Salix nigra*	black willow
Physocarpus opulifolius	common ninebark	*Salix pentandra*	laural willow
Populus angustifolia	narrowleaf cottonwood	*Salix purpurea*	purpleosier willow
Populus balsamifera	balsam poplar	*Salix scouleriana*	scouler's willow
Populus deltoides	eastern cottonwood	*Salix sitchensis*	sitka willow
Populus fremontii	fremont cottonwood	*Sambucus canadensis*	american elder
Populus trichocarpa	black cottonwood	*Sambucus cerulea ssp. mexicana*	mexican elder
Rosa gymnocarpa	baldhip rose	*Sambucus racemosa*	red elderberry
Rosa nutkana	nootka rose	*Sambucus racemosa ssp. pubens*	red elder
Rosa palustris	swamp rose	*Spiraea alba*	meadowsweet spirea
Rosa virginiana	virginia rose	*Spiraea douglasii*	douglas spirea
Rosa woodsii	woods rose	*Symphoricarpos albus*	snowberry
Rubus allegheniensis	allegheny blackberry	*Viburnum dentatum*	arrowwood
Rubus idaeus ssp.strigosus	red raspberry	*Viburnum lantanoides*	hubblebush viburnam
Rubus spectabilis	salmonberry	*Viburnum lentago*	nannyberry
Salix X cottetii	dwarf willow		
Salix amygdaloides	peachleaf willow		

Table 16B–3 Woody plants with poor or fair rooting ability from unrooted cuttings

Scientific name	Common name	Scientific name	Common name
Acer glabrum	dwarf maple	*Fraxinus pennsylvanica*	green ash
Acer negundo	boxelder	*Gleditsia triacanthos*	honeylocust
Acer rubrum	red maple	*Hibiscus aculcatus*	hibiscus
Acer saccharinum	silver maple	*Hibiscus laevis*	halberd-leaf marshmallow
Alnus pacifica	pacific alder	*Hibiscus moscheutos*	common rose mallow
Alnus rubra	red alder	*Hibiscus moscheutos ssp. lasiocarpos*	hibiscus
Alnus serrulata	smooth alder	*Holodiscus discolor*	oceanspray
Alnus viridis ssp.sinuata	sitka alder	*Ilex coriacea*	sweet gallberry
Amelanchier alnifolia var cusickii	cusick's serviceberry	*Ilex decidua*	possomhaw
Amorpha fruitcosa	false indigo	*Ilex glabra*	bitter gallberrry
Aronia arbutifolia	red chokeberry	*Ilex opaca*	american holly
Asimina triloba	pawpaw	*Ilex verticillata*	winterberry
Betula nigra	river birch	*Ilex vomitoria*	yaupon
Betula papyrifera	paper birch	*Juglans nigra*	black walnut
Betula pumila	low birch	*Juniperus virginiana*	eastern redcedar
Carpinis caroliniana	american hornbeam	*Leucothoe axillaris*	leucothoe
Carya aquatica	water hickory	*Lindera benzoin*	spicebush
Carya cordiformis	bitternut hickory	*Liquidambar styraciflua*	sweetgum
Carya ovata	shagbark hickory	*Liriodendron tulipifera*	tulip poplar
Catalpa bignonioides	southern catalpa	*Lyonia lucida*	fetterbush
Celtis laevigata	sugarberry	*Magnolia virginiana*	sweetbay
Celtis occidentalis	hackberry	*Myrica cerifera*	southern waxmyrtle
Cercis canadensis	redbud	*Nyssa aquatica*	swamp tupelo
Chionanthus virginicus	fringetree	*Nyssa ogeeche*	ogeeche lime
Clematis ligusticifolia	western clematis	*Nyssa sylvatica*	blackgum
Clethera alnifolia	sweet pepperbush	*Ostrya virginiana*	hophornbeam
Cornus florida	flowering dogwood	*Persea borbonia*	redbay
Cornus stricta	swamp dogwood	*Philadelphus lewesii*	lewis mockorange
Crataegus douglasii	douglas' hawthorn	*Physocarpus malvaceus*	mallow ninebark
Crataegus mollis	downy hawthorn	*Physocarpus opulifolius*	common ninebark
Cyrilla racemiflora	titi	*Pinus taeda*	loblolly pine
Diospyros virginiana	persimmon	*Planera aquatica*	water elm
Dlaeagnus commutata	silverberry	*Platanus occidentalis*	sycamore
Forestiera acuminata	swamp privet	*Populus tremuloides*	quaking aspen
Fraxinus caroliniana	carolina ash	*Prunus angustifolia*	wild plum
Fraxinus latifolia	oregon ash		

Table 16B–3 Woody plants with poor or fair rooting ability from unrooted cuttings—Continued

Scientific name	Common name	Scientific name	Common mame
Prunus virginiana	common chokecherry	*Rhododendron atlanticum*	coast azalea
Quercus alba	white oak	*Rhododendron viscosum*	swamp azalea
Quercus bicolor	swamp white oak	*Rhus copallina*	flameleaf sumac
Quercus garryana	oregon white oak	*Rhus glabra*	smooth sumac
Quercus laurifolia	swamp laurel oak	*Robinia pseudoacacia*	black locust
Quercus lyrata	overcup oak	*Sambucus cerulea*	blue elderberry
Quercus macrocarpa	bur oak	*Spiraea tomentosa*	hardhack spirea
Quercus michauxii	swamp chestnut oak	*Styrax americanus*	Japanese snowbell
Quercus nigra	water oak	*Taxodium distichum*	bald cypress
Quercus pagoda	cherrybark oak	*Tsuga canadensis*	eastern hemlock
Quercus palustris	pin oak	*Ulmus americana*	american elm
Quercus phellos	willow oak	*Viburnum nudum*	swamp haw
Quercus shumardii	shumard oak	*Viburnum trilobum*	american cranberrybush

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems

Scientific name	Common name	Warm season or noncompetitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Agrostis alba	redtop											
Ammophila breviligulata	American beachgrass		sands	5.5	fair	poor	good			0		1,facu- 2,upl 3,upl*
Andropogon gerardii	big bluestem	yes	loams	6.0	good	poor	poor	fair		0		1,fac 2,fac 3,fac- 4,facu 5,fac- 6,facu 7,fac- 8,facu 9facu
Arundo donax	giant reed		sandy	7.0	good	poor		poor		0	1"	1,facu- 2,facw 3,facw 6,fac+ 7,facw 8,facw 0,facw C,ni H,ni
Elymus virginicus	wildrye	yes noncompetitive	loams	6.0	fair	good	fair	good		0		1,facw-
Eragrostis trichodes	sand lovegrass	yes	sands	6.0	good	poor	poor	poor		0		
Festuca rubra	red fescue	noncompetitive	loams	6.5	good	good	poor	fair		0		1,facu

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Hemarthria altissima	limpograss		sandy		poor	poor	poor	good		0	1'	1,facw 2,facw 6,facw
Panicum amarulum	coastal panicgrass	yes	sands to loams	5.5	good	poor	fair	good		0		1,facu- 2,fac 6,facu-
Panicum clandestinum	deertongue	yes										
Panicum virgatum	switchgrass	yes	loams to sands	6.0	good	poor	fair	good	all	0		1,fac 2,fac+ 3,fac+ 4,fac 5,fac 6,facw 7,fac+ 8,fac 9,fac+ H,ni
Paspalum vaginatum	seashore paspalum		sandy			poor		good		1/2'	1'	2,obl 6,facw* C,ni H,ni
Pennisetum purpureum	elephant-grass					poor				0	2'	2,facu+ C,ni H,ni

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Poa pratensis	Kentucky bluegrass		loam	6.5	poor	poor	poor	fair		0		1,facu
Schizachyrium scoparium	little bluestem	yes	sands to loams	6.5	good	poor	poor	poor		0		1,facu
Sorghastrum nutans	Indiangrass	yes	sands to	6.5	fair	poor	poor	poor		0		1,upl
Spartina pectinata	prairie cordgrass	yes	sands to loams	6.0	good	fair	fair	fair		0	1"	1,obl 2,obl 3,facw+ 4,facw 5,facw 6,facw+ 7,facw 8,obl 9,obl
Zizaniopsis miliacea	giant cutgrass		loam	4.3-6.0	poor	poor		good	all	1/2'	2'	1,obl 2,obl 3,obl 6,obl

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/

1/ Wetland indicator terms (from USDI Fish and Wildlife Service's National List of Plant Species That Occur in Wetlands, 1988):

Region code number or letter:
- **1** Northeast (ME, NH, VT, MA, CT, RI, WV, KY, NY, PA, NJ, MD, DE, VA, OH)
- **2** Southeast (NC, SC, GA, FL, TN, AL, MS, LA, AR)
- **3** North Central (MO, IA, MN, MI, WI, IL, IN)
- **4** North Plains (ND, SD, MT (eastern), WY (eastern))
- **5** Central Plains (NE, KS, CO (eastern))
- **6** South Plains (TX, OK)
- **7** Southwest (AZ, NM)
- **8** Intermountain (NV, UT, CO (western))
- **9** Northwest (WA, OR, ID, MT (western), WY (western))
- **0** California (Ca)
- **A** Alaska (AK)
- **C** Caribbean (PR, VI, CZ, SQ)
- **H** Hawaii (HI, AQ, GU, IQ, MQ, TQ, WQ, YQ)

Indicator categories (estimated probability):
- **fac** Facultative—Equally likely to occur in wetlands or nonwetlands (34-66%).
- **facu** Facultative upland—Usually occur in nonwetlands (67-99%), but occasionally found in wetlands (1-33%)
- **facw** Facultative wetland—Usually occur in wetlands (67-99%), but occasionally found in nonwetlands.
- **obl** Obligate wetland—Occur almost always (99%) under natural conditions in wetlands.
- **upl** Obligate upland—Occur in wetlands in another region, but occur almost always (99%) under natural conditions in nonwetlands in the region specified. If a species does not occur in wetlands in any region, it is not on the National List.

Frequency of occurrence:
- **–** (negative sign) indicates less frequently found in wetlands.
- **+** (positive sign) indicates more frequently found in wetlands.
- ***** (asterisk) indicates wetlands indicators were derived from limited ecological information.
- **ni** (no indicator) indicates insufficient information was available to determine an indiator status.

United States
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**Soil
Conservation
Service**

Engineering
Field
Handbook

Chapter 18 Soil Bioengineering for Upland Slope Protection and Erosion Reduction

(210-EFH, 10/92)

Issued October 1992

Cover: Live plant cuttings are installed (top photo) on upland slopes to provide soil reinforcement and reduce surface erosion. The bottom photo shows the slope after 1 year. (Photos: Robbin B. Sotir & Associates)

United States Department of Agriculture

Soil Conservation Service

P.O. Box 2890
Washington, D.C.
20013

December 23, 1992

NATIONAL ENGINEERING FIELD HANDBOOK EFH-1B
210-VI

SUBJECT: ENG - ENGINEERING FIELD HANDBOOK (EFH), PART 650, CHAPTER 18 - "SOIL BIOENGINEERING FOR UPLAND SLOPE PROTECTION AND EROSION REDUCTION"

Purpose. To distribute copies of the subject technical publication.

Effective Date. Effective upon receipt.

This new chapter of the Engineering Field Handbook (EFH) provides field personnel with an interdisciplinary guide for application of soil bioengineering technology. National in scope, it describes related principles, practice characteristics, design, construction materials and techniques appropriate for upland slope protection and erosion reduction. Soil bioengineering systems, which utilize living plant materials as structural components, offer technology for achieving many natural resource conservation objectives including land stabilization and restoration, wildlife habitat improvement, erosion reduction, and water quality improvement. Similar technology for streambank and shoreline protection will be addressed in a forthcoming, newly revised Chapter 16 of the EFH.

Representing an addition to Part 650, EFH, this chapter reflects a continuation of the new format and look for National engineering technical directives.

Filing Instructions. This material should be filed as a new chapter in the EFH, Part 650 of the National Engineering Handbook Series (NEHS). Chapters of the existing Engineering Field Manual (EFM) should continue to be used until new chapters are issued. An outline of the new organization for the NEHS is shown on the second page of this transmittal. Additional copies of EFH, Chapter 18, may be obtained by ordering EFH-1B from the Consolidated Forms and Distribution Center, 3222 Hubbard Road, Landover, Maryland 20785.

Edgar H. Hanson
For

ROBERT R. SHAW
Deputy Chief for Technology

Enclosure

DIST: (See Attached List)

National Engineering Handbook Series
Table of Contents

Preface

Chapter 18, Soil Bioengineering for Upland Slope Protection and Erosion Reduction is one of the 18 chapters of the U.S. Department of Agriculture Soil Conservation Service (SCS) Engineering Field Handbook, previously referred to as the Engineering Field Manual. Other chapters that are pertinent to, and should be referenced in use with, chapter 18 are:

Chapter 1: Engineering Surveys
Chapter 2: Estimating Runoff
Chapter 3: Hydraulics
Chapter 4: Elementary Soils Engineering
Chapter 5: Preparation of Engineering Plans
Chapter 6: Structures
Chapter 7: Grassed Waterways and Outlets
Chapter 8: Terraces
Chapter 9: Diversions
Chapter 10: Gully Treatment
Chapter 11: Ponds and Reservoirs
Chapter 12: Springs and Wells
Chapter 13: Wetland Restoration, Enhancement, or Creation
Chapter 14: Drainage
Chapter 15: Irrigation
Chapter 16: Streambank and Shoreline Protection
Chapter 17: Construction and Construction Materials

This is the first edition of chapter 18. The science of soil bioengineering is rapidly evolving and improving; therefore, additions to and modifications of this chapter will be made as necessary.

Acknowledgments

This chapter was prepared under the guidance of **Ronald W. Tuttle**, national landscape architect, and steering committee members **David C. Ralston**, national design engineer, and **Curtis W. Sharp**, national plant materials specialist, SCS, Washington, DC.

Robbin B. Sotir & Associates and **Dr. Donald H. Gray** are the principal authors of this manuscript. They supplied original drawings, which were adapted for SCS use, and all photographs. **Carolyn A. Adams**, landscape architect; **Leland M. Saele**, design engineer; **Gary E. Formanek**, agricultural engineer; and **Frank F. Reckendorf**, sedimentation geologist; SCS West National Technical Center, Portland, Oregon, edited the manuscript to extend its applicability to most geographic regions and to fit it to agency programs. Other staff members at the SCS National Technical Centers and State Offices also contributed by reviewing the chapter and providing comments.

Sarah Laurent, editor, SCS, Washington, DC, provided editing assistance, and **Wendy R. Oller**, illustrator, SCS, Fort Worth, Texas, provided desktop publishing in preparation for printing.

Chapter 18 Soil Bioengineering for Upland Slope Protection and Erosion Reduction

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650.1800 Introduction

(a) Purpose and scope

Chapter 18 provides field personnel with a guide for soil bioengineering intended primarily for upland slope protection and erosion reduction. It describes characteristics, principles, design, and construction techniques of soil bioengineering. Two approaches to soil bioengineering techniques are presented: woody vegetative systems and woody vegetative systems combined with simple structures. Woody vegetative systems are emphasized. Vegetative plantings and vegetated structures are discussed cursorily to help distinguish them from soil bioengineering techniques.

This chapter is national in scope and should be supplemented with regional and local information. Soil bioengineering measures, such as live cribwalls and brushlayering, are relatively complex and must be tailored carefully to specific soil and site conditions. The contents of this chapter are not directly applicable to massive erosion problems or complex shallow slope failure problems. Additional background on specific designs and sample calculations are available in other sources (Gray, et.al. 1982).

Planning and design of soil bioengineering systems generally require a team of experts. Therefore, the scope of this chapter reflects the interdisciplinary nature of soil bioengineering.

(b) Background

Soil bioengineering, in the context of upland slope protection and erosion reduction, combines mechanical, biological, and ecological concepts to arrest and prevent shallow slope failures and erosion. Basic approaches to upland slope protection and erosion control can be divided into two general categories: living and nonliving (table 18–1).

The **living approach**, which uses live plant materials, can be further divided into two specific categories: vegetative plantings and soil bioengineering. Vegetative plantings are conventional plantings of grasses, forbs, and shrubs used to prevent surface erosion. Soil bioengineering utilizes live plant parts to provide soil reinforcement and prevent surface erosion (fig. 18–1). In soil bioengineering systems, the installation may play the major structural roles immediately or may become the major structural component over time.

Live staking, live fascines, brushlayers, branchpacking, and live gully repair are soil bioengineering techniques that use stems or branch parts of living plants as initial and primary soil reinforcing and stabilizing material. When these vegetative cuttings are placed in the ground, roots develop and foliage sprouts. The resulting vegetation becomes a major structural component of the bioengineering system.

Live cribwalls, vegetated rock gabions, vegetated rock walls, and joint plantings are soil bioengineering techniques that use porous structures with openings through which vegetative cuttings are inserted and established. The inert structural elements provide immediate resistance to sliding, erosion, and washout. As vegetation becomes established, roots invade and permeate the slope, binding it together into a unified, coherent mass. Over time, the structural elements diminish in importance as the vegetation increases in strength and functionality.

Nonliving approaches use rigid constructions, such as surface armoring, gravity retaining walls, and rock buttresses. Vegetation can be used in conjunction with nonliving structures to create vegetated structures. Vegetation enhances the structures and helps reduce surface erosion, but usually does not provide any reinforcement benefits.

(c) Integrated planning and design requirements

Soil bioengineering combines biological elements with engineering design principles. The requirements for both must be considered when planning and designing the measures presented in table 18–1. For example, engineering requirements may dictate highly compacted soil for fill slopes, while plants prefer relatively loose soil. Using a sheep's foot roller for compaction is a solution that would integrate biological and engineering requirements because it compacts the soil, but also allows plant establishment in resulting depressions in the slope. Differing needs can generally be integrated through creative approaches and occasional compromises in planning and design.

(d) Applications

The soil bioengineering techniques in this document are generally appropriate for immediate protection of slopes against surface erosion, shallow mass wasting, cut and fill slope stabilization, earth embankment protection, and small gully repair treatment. Appropriate application of specific measures are discussed in detail in Section 650.1803, Construction techniques and materials.

Other situations where soil bioengineering measures can be employed are not discussed in this chapter. These situations include dune stabilization, wetland buffers, reservoir drawdown areas where plants can be submerged for extended periods, and areas with highly toxic soils. Properly designed and constructed soil bioengineering measures have also been employed with considerable success in stabilizing shorelines and streambanks. This topic is addressed in EFH, Chapter 16, Streambank and Shoreline Protection.

Table 18–1 Approaches to upland slope protection and erosion control

	Category	Examples	Appropriate uses	Role of vegetation
LIVING	**Vegetative plantings**			
LIVING	Conventional plantings	Grass seedlings Transplants Forbs	Control water and wind erosion. Minimize frost effects.	Control weeds. Bind & restrain soil. Filter soil from runoff. Intercept raindrops. Maintain infiltration. Moderate ground temperature.
LIVING	**Soil bioengineering**			
LIVING	Woody plants used as reinforcement, as barriers to soil movements, & in the frontal openings or interstices of retaining structures.	Live staking Live fascine Brushlayer Branchpacking Live cribwall Live gully repair Vegetated rock gabion Vegetated rock wall Joint planting	Control of rills & gullies. Control of shallow (translational) mass movement. Filter sediment. Improved resistance to low to moderate earth forces.	Same as above, but also reinforce soil, transpire excess water, & minimize downslope movement of earth masses. Reinforce fill into monolithic mass. Improve appearance and performance of structure.
NONLIVING	**Vegetated structures**			
NONLIVING	Inert structures with vegetative treatments.	Wall or revetment with slope face planting. Tiered structures with bench planting.	Control erosion on cut & fill slopes subject to scour & undermining.	Stop or prevent erosion & shallow sloughing on or at the slope face above the toe.
NONLIVING	**Rigid construction**	(see Chapter 6, Structures, of the Engineering Field Handbook).		

Figure 18–1 Soil bioengineering provides soil reinforcement and reduces surface erosion (Robbin B. Sotir & Associates photos)

Figure 18–1a Eroding fill slope

Figure 18–1b Measures being installed

Figure 18–1c Installation 1 year later

650.1801 Characteristics of soil bioengineering systems

Soil bioengineering uses particular characteristics of vegetative components and integrates specific characteristics of structures with vegetation. The resulting systems and their components have benefits and limitations that need to be considered prior to selecting them for use.

(a) Vegetative components

(1) Herbaceous species

Herbaceous vegetation, especially grasses and forbs, offers long-term protection against surface (water and wind) erosion on slopes. It provides only minor protection against shallow mass movement. Vegetation helps to prevent surface erosion by:

- Binding and restraining soil particles in place
- Reducing sediment transport
- Intercepting raindrops
- Retarding velocity of runoff
- Enhancing and maintaining infiltration capacity
- Minimizing freeze-thaw cycles of soils susceptible to frost

Herbaceous species are almost always used in conjunction with soil bioengineering projects to add protection against surface erosion.

(2) Woody species

More deeply rooted woody vegetation provides greater protection against shallow mass movement by:

- Mechanically reinforcing the soil with roots
- Depleting soil-water through transpiration and interception
- Buttressing and soil arching action from embedded stems

Live fascines, for example, provide many of these protective functions. They are fabricated from woody species, such as shrub willow or shrub dogwood, into sausage-like bundles, which are placed with the stems oriented generally parallel to the slope contour. This method of placement and orientation would not be used in slope reinforcement. Live fascines serve to dissipate the energy of downward moving water by trapping debris and providing a series of benches on which grasses, seedlings, and transplants establish more easily. Portions of the live fascines also root and become part of the stabilizing cover. Live fascines provide an immediate increase in surface stability and can further improve soil stability to depths of 2 to 3 feet as roots develop.

In the case of brushlayering, live branches or shoots of such woody species as shrub willow, dogwood, or privet are placed in successive layers with the stems generally oriented perpendicular to the slope contour, as shown in figure 18–1. This orientation is the optimal direction for maximum reinforcing effect in a slope. Brushlayering can improve soil stability to depths of 4 to 5 feet.

(b) Structural components

Properly designed and installed structures help to stabilize a slope against shallow mass movement and protect the slope against rill and gully formation. Structures also play a critical role in the establishment of vegetation on steep slopes or in areas subject to severe erosion. They may make it possible to establish plants on slopes steeper than would normally be possible. Structures stabilize slopes during the critical time for seed germination and root growth. Without this stabilization, vegetative plantings would fail during their most vulnerable time.

(1) Materials

Structures can be built from natural or manufactured materials. Natural materials, such as earth, rock, stone, and timber, usually cost less, are environmentally more compatible, and are better suited to vegetative treatment or slight modifications than are manufactured materials. Natural materials may also be available onsite at no cost.

Some structures are comprised of both natural and manufactured materials. Examples include concrete cribwalls, steel bin walls, gabion walls or revetments, welded wire or polymeric geogrid walls, and reinforced earth. In these cases steel and concrete mostly provide rigidity, strength, and reinforcement, whereas stone, rock, and soil provide mass. These types of

structures have spaces that are often planted with herbaceous or woody vegetation.

(2) Retaining structures

A retaining structure of some type is usually required to protect and stabilize extremely steep slopes. Low retaining structures at the toe of a slope make it possible to grade the slope back to a more stable angle that can be successfully revegetated without loss of land at the crest. Structures are generally capable of resisting much higher lateral earth pressures and shear stresses than vegetation.

(3) Grade stabilization structures

Grade stabilization structures are used to control and prevent gully erosion. A grade stabilization structure reduces the grade above it and dissipates the excess energy of flowing water within the structure itself. Debris and sediment tend to be deposited and trapped upstream of the structure. This, in turn, permits establishment of vegetation behind the structure, which further stabilizes the ground. Grade stabilization structures may range from a series of simple timber check dams to complex concrete overfall structures and earth embankments with pipe spillways.

Gully control provides a good example of the integration of structures and vegetation. Structural measures may be required in the short term to stabilize critical locations. The long-term goal is to establish and maintain a vegetative cover that prevents further erosion. This goal is seldom realized unless the severe gully conditions can be altered immediately. Vegetation alone, for example, will rarely stabilize gully headcuts because of the concentrated water flow, overfalls, and pervasive forces that promote gully enlargement in an unstable channel system. Initially, the vegetation and the structure work together in an integrated fashion. The ultimate function of these structures, however, is to help establish vegetation which will provide long-term protection.

(c) Attributes and limitations

Soil bioengineering measures should not be viewed as a panacea or solution for all slope failure and surface erosion problems. Soil bioengineering has unique attributes, but is not appropriate for all sites and situations. In certain cases, a conventional vegetative treatment (e.g., grass seeding and hydro mulching) works satisfactorily at less cost. In other cases, the more appropriate and most effective solution is a structural retaining system alone or in combination with soil bioengineering.

The following specific attributes and limitations should be considered before applying a soil bioengineering technique:

(1) Environmental compatibility

Soil bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation. These are generally priority considerations in environmentally sensitive areas, such as parks, woodlands, riparian areas, and scenic corridors where aesthetic quality, wildlife habitat, and similar values may be critical (fig. 18–2).

(2) Cost effectiveness

Field studies have shown instances where combined slope protection systems have proven more cost effective than the use of either vegetative treatments or structural solutions alone. Where construction methods are labor intensive and labor costs are reasonable, the combined systems may be especially cost effective. Where labor is either scarce or extremely expensive, however, soil bioengineering systems may be less practical than structural measures.

Using indigenous materials accounts for some of the cost effectiveness because plant costs are limited to labor for harvesting and handling and direct costs for transporting the plants to the site.

(3) Planting times

Soil bioengineering systems are most effective when they are installed during the dormant season, usually the late fall, winter, and early spring. This often coincides with the time that other construction work is slow.

Constraints on planting times or the availability of the required quantities of suitable plant materials during allowable planting times may limit the usefulness of soil bioengineering methods.

(4) Difficult sites

Soil bioengineering is often a useful alternative for small, highly sensitive, or steep sites where the use of machinery is not feasible and hand labor is a necessity.

However, rapid vegetative establishment may be difficult on extremely steep slopes.

The usefulness of soil bioengineering methods may be limited by the available medium for plant growth, such as rocky or gravelly slopes that lack sufficient fines or moisture to support the required plant growth. In addition, soil-restrictive layers, such as hardpans, may prevent required root growth.

The biotechnical usefulness of vegetation would be limited on slopes that are exposed to high velocity water flow or constant inundation.

(5) Harvesting local plant material

Appropriate vegetation is often obtained from local stands of willows and other suitable species. This stock is already well suited to the climate, soil conditions, and available moisture and is a good candidate for survival. While harvesting may often help a beneficial species proliferate, reliance on the use of local plant materials and gathering in the wild could result in short supplies or unacceptable depletion of site vegetation. Furthermore, some localities have prohibitions against gathering native plants, and materials must be purchased from commercial sources.

Figure 18–2 Newly established installation provides multiple functions and values (Robbin B. Sotir & Associates photo)

(6) Biotechnical strengths

Soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. In some instances, the primary role of the structural component is to give the vegetation a better chance to become established. It has been shown in slope reconstruction projects that soil bioengineering systems can withstand heavy rainfalls immediately after installation. Even if established vegetation dies, the plant roots and surface residue may continue to play an important protective role during reestablishment.

(7) Maintenance requirements

Once vegetation is well established on a soil bioengineering project, usually within one growing season, it generally becomes self-repairing by regeneration and growth and requires little maintenance. However, a newly installed soil bioengineering project will require careful periodic inspections until it is established. Establishing vegetation is vulnerable to trampling, drought, grazing, nutrient deficiencies, toxins, and pests, and may require special management measures at times.

650.1802 Basic principles and design considerations

(a) Basic principles of soil bioengineering

The basic principles that apply to conventional soil erosion control also apply in general to soil bioengineering. These principles are mostly common sense guidelines that involve planning, timing, and minimizing site disturbance rather than the design of individual measures themselves. Applicable principles can be summarized as follows:

(1) Fit the soil bioengineering system to the site

This means considering site topography, geology, soils, vegetation, and hydrology. Avoid extensive grading and earthwork in critical areas and perform soil tests to determine if vigorous plant growth can be supported. At a minimum, collect the following information:

(i) Topography and exposure

- Note the degree of slope in stable and unstable areas. Also note the presence or lack of moisture. The likely success of soil bioengineering treatments can best be determined by observing existing stable slopes in the vicinity of the project site.
- Note the type and density of existing vegetation in areas with and without moisture and on slopes facing different directions. Certain plants grow well on east-facing slopes, but will not survive on south-facing slopes.
- Look for areas of vegetation that may be growing more vigorously than other site vegetation. This is generally a good indicator of excess moisture, such as seeps and a perched water table, or it may reflect a change in soils.

(ii) Geology and soils

- Consult SCS geologists about geologic history and types of deposits (colluvium, glacial, alluvium, other).
- Note evidence of past sliding. If site evidence exists, determine whether the slide occurred along a deep or shallow failure surface. Leaning

or deformed trees may indicate previous slope movement or downhill creep. In addition to site evidence, check aerial photos, which can reveal features that may not be apparent from a site visit.

- Determine soil type and depth. Use the soil survey report, if available, or consult SCS soil scientists.

(iii) Hydrology

- Determine the drainage area associated with the problem area. Note whether water can be diverted away from the problem area.
- Determine the annual precipitation. Are there concentrated discharges?
- Calculate peak flows or mean discharge through the project area.
- If a seep area was noted, locate the source of the water. Determine whether the water can be intercepted and diverted away from the slope face.

(2) Retain existing vegetation whenever possible

Vegetation provides excellent protection against surface erosion and shallow slope failures. Soil bio-engineering measures are designed to aid or enhance the reestablishment of vegetation.

(3) Limit removal of vegetation

- Limit cleared area to the smallest practical size
- Limit duration of disturbance to the shortest practical time
- Remove and store existing woody vegetation that may be used later in the project
- Schedule land clearing during periods of low precipitation whenever possible

(4) Stockpile and protect topsoil

Topsoil removed during clearing and grading operations can be reused during planting operations.

(5) Protect areas exposed during construction

Temporary erosion and sediment control measures can be used.

(6) Divert, drain, or store excess water

- Install a suitable system to handle increased and/or concentrated runoff caused by changed soil and surface conditions during and after construction.
- Install permanent erosion and sediment control measures in the project before construction is started if possible.

(b) Design considerations

(1) Earthwork

Typically, sites require some earthwork prior to the installation of soil bioengineering systems. A steep undercut or slumping bank, for example, requires grading to flatten the slope for stability. The degree of flattening depends on the soil type, hydrologic conditions, geology, and other site factors.

(2) Scheduling and timing

Planning and coordination are needed to achieve optimal timing and scheduling. The seasonal availability of plants or the best time of year to install them may not coincide with the construction season or with tight construction schedules. In some cases, rooted stock may be used as an alternative to unrooted dormant season cuttings.

(3) Vegetative damage to inert structures

Vegetative damage to inert structures may occur when inappropriate species or plant materials that exceed the size of openings in the face of structures are used. Vegetative damage does not generally occur from roots. Plant roots tend to avoid porous, open-faced retaining structures because of excessive sunlight, moisture deficiencies, and the lack of a growing medium.

(4) Moisture requirements and effects

The backfill behind a stable retaining structure has certain specified mechanical and hydraulic properties. Ideally, the fill is coarse-grained, free-draining, granular material. Excessive amounts of clay, silt, and organic matter are not desirable. Free drainage is essential to the mechanical integrity of an earth-retaining structure and also important to vegetation, which cannot tolerate waterlogged soil conditions. The establishment and maintenance of vegetation, however, usually requires the presence of some fines and organic matter in the soil to provide adequate moisture and nutrient retention. In many instances,

these biological requirements can be satisfied without compromising engineering performance of the structure. With cribwalls, for example, adequate amounts of fines or other amendments can be incorporated into the backfill. Gabions can be filled with rock and soil drifted into them to facilitate growth of vegetation. Woody vegetative cuttings can be placed between the baskets during filling and into the soil or backfill beyond the baskets. The needs of plants and the requirements of structures must be taken into account when designing a system.

650.1803 Construction techniques and materials

(a) General considerations

Soil bioengineering measures have certain requirements and capabilities. Plant species must be suitable for the intended use and adapted to the site's climate and soil conditions. Consult a plant materials specialist about available cultivars to ensure that appropriate species are used. Species that root easily, such as willow, are required for such measures as live fascines, brushlayer, and live staking or where unrooted stems are used with structural measures. Table 18–2 is a general listing of plant species used in soil bioengineering.

Table 18–2 Soil bioengineering plant species

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Acer negundo Boxelder	N, NE	Common	Excellent	Small tree	Mod. deep spreading	Poor-fair
Alnus rubra Red alder	NW	Very common	Excellent	Large tree	Shallow spreading	Poor
Baccharis glutinosa Water wally	W	Common	Very good	Medium shrub	Fibrous	Good
Baccharis halimifolia Eastern baccharis	S, SE	Common	Very poor	Small-med. shrub	Fibrous	Fair-good
Baccharis pilularis Coyotebrush	W	Very common	Good	Medium shrub	Fibrous	Good
Baccharis viminea Mule fat	W	Very common	Very good	Medium shrub	Fibrous	Good
Betula papyrifera Paper birch	N, E, & W	Common	Good	Tree	Fibrous shallow	Poor
Betula pumila Low birch	N, E, & W	Common	Very good	Medium shrub	Fibrous	Poor

Table 18–2 Soil bioengineering plant species—Continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Cornus amomum Silky dogwood	N, SE	Very common	Very good	Small shrub	Shallow fibrous	Very good
Cornus racemosa Gray dogwood	NE	Common	Very good	Med-small shrub	Shallow	Good
Cornus rugosa Roundleaf dogwood	NE	Common	Very good	Med-small shrub	Shallow fibrous	Fair-good
Cornus sericea ssp. stolonifera Red osier dogwood	N, NE, & NW	Very common	Very good	Med-small shrub	Shallow	Very good
Crataegus Sp. Hawthorn	SE	Uncommon	Good	Sm. dense tree	Top root	Fair
Elaeagnus commutata Silverberry	N. Cent.	Very Common	Poor	Medium shrub	Shallow	Fair-good
Ligustrum sinense Chinese privet	S, SE	Common	Fair-good	Small-med. shrub	Shallow fibrous	Good
Lonicera involucrata Black twinberry	E	Common	Poor-fair	Small shrub	Shallow	Good
Physocarpus capitatus Pacific ninebark	NW, W	Common	Fair	Small	Fibrous	Good
Physocarpus opulifolius Common ninebark	NE	Common	Good	Med-high shrub	Shallow lateral	Fair-good
Populus angustifolia Arrowleaf cottonwood	W	Common	Good	Tree	Shallow	Very good
Populus balsamifera ssp. trichocarpa Black cottonwood	NW	Common	Good	Tree	Shallow fibrous	Very good
Populus deltoides Eastern cottonwood	MW, E	Very common	Good	Large tree	Shallow	Very good
Populus fremontii Fremont cottonwood	SW	Very common	Good	Tree	Shallow fibrous	Very good

Table 18–2 Soil bioengineering plant species—Continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Populus tremuloides Quaking aspen	NW	Very common	Good	Large tree	Shallow	Fair
Robinia pseudoacacia Black locust	NE	Common	Very poor	Tree	Shallow	Good
Rubus allegheniensis Allegheny blackberry	NE	Very common	Very good	Small shrub	Fibrous	Good
Rubus spectabilis Salmonberry	SW	Very common	Good	Small shrub	Fibrous	Fair-good
Rubus strigosus Red raspberry	N, NE, & W	Very common	Very good	Small shrub	Fibrous	Good
Salix exigua Coyote willow	NW	Fairly common	Good	Medium shrub	Shallow suckering	Good
ssp. interior Sandbar willow	N, SE	Common	Good	Large shrub	Shallow to deep	Fair-good
Salix amygdaloides Peachleaf willow	N, S	Common	Good	Very large shrub	Shallow to deep	Very good
Salix bonplandiana Pussy willow	W & MW	Very common	Good	Medium shrub	Fibrous	Very good
Salix eriocephala ssp. ligulifolia Erect willow	NW	Common	Good	Large shrub	Fibrous	Very good
Salix gooddingii Goodding willow	SW	Very common	Good	Large shrub Small tree	Shallow to deep	Excellent
Salix hookeriana Hooker willow	NW	Common	Good	Large	Fibrous dense	Very good
Salix humilis Prairie willow	N, NE	Very common	Good	Medium shrub	Fibrous	Good
Salix lasiolepis Arroya willow	W	Common	Good	Medium shrub	Fibrous	Very good

Table 18–2 Soil bioengineering plant species—Continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Salix lemmonii Lemmon willow	W	Common	Good	Medium shrub	Fibrous	Very good
Salix lucida Shining willow	N, NE	Very common	Good	Med-large shrub	Fibrous	Very good
ssp. lasiandra Pacific willow	NW	Very common	Good	Large shrub Small tree	Fibrous	Very good
Salix lutea Yellow willow	W	Very common	Good	Med-large shrub	Fibrous	Very good
Salix nigra Black willow	N, SE	Very common	Good	Large shrub Small tree	Shallow to deep	Excellent
Salix purpurea Streamco	N, S, E, & W	Very common	Very good	Medium shrub	Shallow	Very good
Salix scouleriana Scoulers willow	NE	Very common	Good	Large shrub Small tree	Shallow	Very good
Salix sitchensis Sitka willow	NW	Common	Good	Very large shrub	- - -	Very good
Salix X cotteti Bankers willow	N, S, E, & W	Uncommon	Good	Small shrub	Shallow	Very good
Salix discolor Red willow	N, NE	Very common	Good	Large shrub	Shallow	Very good
Sambucus cerulea Blueberry elderberry	W	Common	Very good	Medium shrub	Fibrous	Poor
Sambucus canadensis American elderberry	NE, SE	Very common	Very good	Medium shrub	Fibrous	Good
Sambucus racemosa Red elderberry	NW	Common	Good	Medium shrub	- - -	Good
ssp. pubens Scarlet elder	NE	Common	Very good	Medium shrub	Deep laterals	Fair-good
Spiraea alba Meadowsweet spirea	N, E	Common	Good	Small dense tree	Dense shallow lateral	Fair-good

Table 18–2 Soil bioengineering plant species—Continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Spiraea douglasii Douglas spirea	NW	Common	Fair	Dense shrub	Fibrous suckering	Good
Spiraea tomentosa Hardhack spirea	NE	Common	Good	Small shrub	Dense shallow	Fair
Symphoricarpos albus Snowberry	N, NW, & E	Common	Good	Small shrub	Shallow fibrous	Good
Viburnum alnifolium Hubbiebush viburnum	NE	Fairly common	Good	Large shrub	Shallow fibrous	Good
Viburnum dentatum Arrowwood viburnum	E	Common	Good	Medium shrub	Shallow fibrous	Good
Viburnum lentago Nannyberry viburnum	S, SE	Fairly common	Good	Large shrub	Shallow	Fair-good

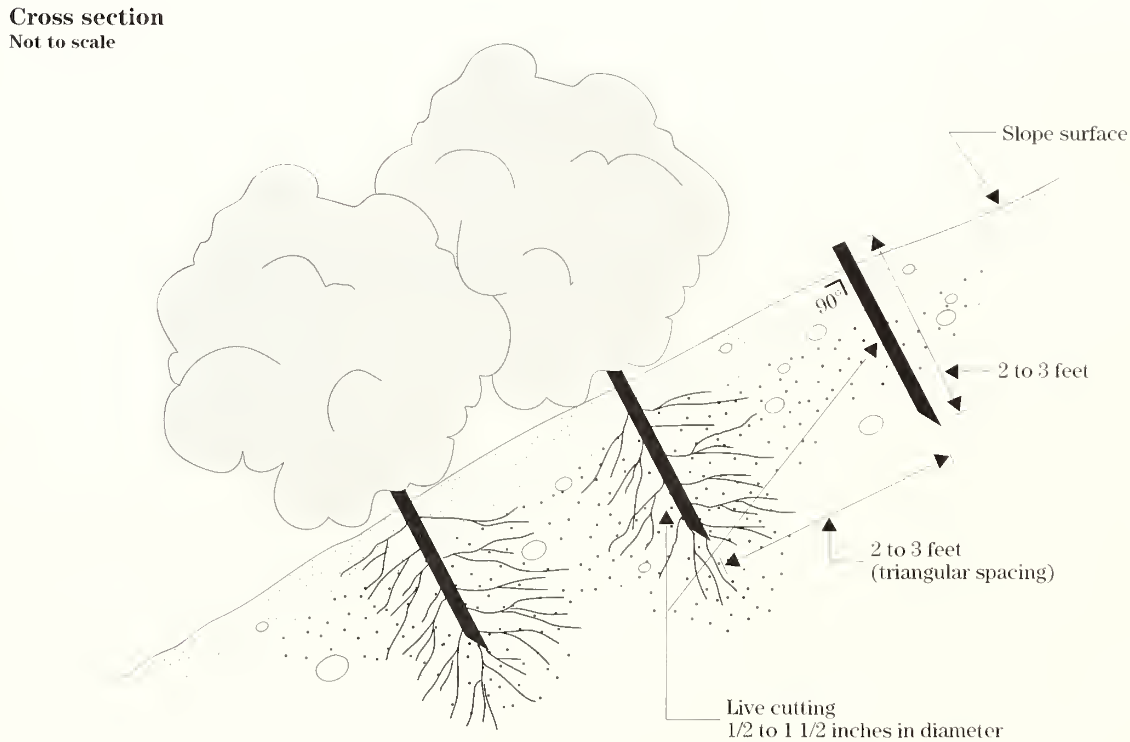
Rooted plants and vegetative cuttings are living materials and must be handled properly to avoid excess stress, such as drying or exposure to heat. They must be installed in moist soil and adequately covered. The soil must be compacted to eliminate or minimize air pockets around the buried stems. If soils are not at or near moisture capacity, the installation must be delayed unless deep and regular irrigation can be provided during and following installation.

Installation of soil bioengineering systems is best accomplished in the late fall at the onset of plant dormancy, in the winter as long as the ground is not frozen, or in early spring before growth begins. In some cases installation after initial spring growth may be successful if extreme care is used, but the risks of failure are high. Summer installation is not recommended. Rooted plants can be used, but they are sometimes less effective and more expensive.

All installations should be inspected regularly and provisions made for prompt repair if needed. Initial failure of a small portion of a system normally can be repaired easily and inexpensively. Neglect of small failures, however, can often result in the failure of large portions of a system.

Properly designed and installed vegetative portions of systems will become self-repairing to a large extent. Periodic pruning and replanting may be required to maintain healthy and vigorous vegetation. Structural elements, such as cribwalls, rock walls, and gabions,

Figure 18–3 Live stake installation



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

may require maintenance and/or replacement throughout their life. Where the main function of structural elements is to allow vegetation to become established and take over the role of slope stabilization, the eventual deterioration of the structures is not a cause for concern.

(b) Soil bioengineering techniques

The following describes soil bioengineering techniques. Their applications, effectiveness, and construction guidelines are also presented.

(1) Live stake

(i) Description—Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground (fig. 18–3). If correctly prepared and placed, the live stake will root and grow (fig. 18–4).

A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Most willow species root rapidly and begin to dry out a slope soon after installation. This is an appropriate technique for repair of small earth slips and slumps that frequently are wet.

Figure 18–4 Top growth and root development of a 7-month-old live stake (Robbin B. Sotir & Associates photo)

(ii) Applications and effectiveness:

- A technique for relatively uncomplicated site conditions when construction time is limited and an inexpensive method is necessary.
- May be used for pegging down surface erosion control materials.
- Enhances conditions for natural invasion and the establishment of other plants from the surrounding plant community.
- Can be used to stabilize intervening area between other soil bioengineering techniques, such as live fascines.

(iii) Construction guidelines

Live material sizes—The cuttings are usually 1/2 to 1 1/2 inches in diameter and 2 to 3 feet long, as shown in figure 18–5. For final size determination, refer to the available cutting source. Figure 18–6 shows a rooted, healthy live stake.

Live material preparation

- The materials must have side branches cleanly removed and the bark intact.
- The basal ends should be cut at an angle for easy insertion into the soil. The top should be cut square.
- Materials should be installed the same day that they are prepared.

Figure 18–5 A prepared live stake (note angled basal end and flat top end) (Robbin B. Sotir & Associates photo)

Installation

- Tamp the live stake into the ground at right angles to the slope. The installation may be started at any point on the slope face.
- The live stakes should be installed 2 to 3 feet apart using triangular spacing. The density of the installation will range from 2 to 4 stakes per square yard.
- The buds should be oriented up.
- Four-fifths of the length of the live stake should be installed into the ground and soil firmly packed around it after installation.
- Do not split the stakes during installation. Stakes that split should be removed and replaced.
- An iron bar can be used to make a pilot hole in firm soil. Drive the stake into the ground with a dead blow hammer (hammer head filled with shot or sand).

Figure 18–6 A live stake that has rooted and is demonstrating healthy growth (Robbin B. Sotir & Associates photo)

(2) Live fascine

(i) Description—Live fascines are long bundles of branch cuttings bound together into sausage-like structures (fig. 18–7).

When cut from appropriate species and properly installed with live and dead stout stakes, they will root and immediately begin to stabilize slopes. They should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow face sliding. This system, installed by a trained crew, does not cause much site disturbance (fig. 18–8)

(ii) Applications and effectiveness

- An effective stabilization technique for slopes.
- Protects slopes from shallow slides (1 to 2 foot depth).
- Immediately reduces surface erosion or rilling.
- Suited to steep, rocky slopes, where digging is difficult.
- Capable of trapping and holding soil on the face of the slope, thus reducing a long slope into a series of shorter slopes.
- Enhances vegetative establishment by creating a microclimate conducive to plant growth.

(iii) Construction guidelines

Live materials—Cuttings must be from species, such as young willows or shrub dogwoods, that root easily and have long, straight branches.

Live material sizes and preparation

- Cuttings tied together to form live fascine bundles vary in length from 5 to 30 feet or longer, depending on site conditions and limitations in handling.
- The completed bundles should be 6 to 8 inches in diameter, with all of the growing tips oriented in the same direction. Stagger the cuttings in the bundles so that tops are evenly distributed throughout the length of the uniformly sized live fascine.
- Live stakes should be 2 1/2 feet long in cut slopes and 3 feet long in fill slopes.

Figure 18–7 Fabrication of a live fascine bundle (Robbin B. Sotir & Associates photo)

Figure 18–8 A live fascine system (Robbin B. Sotir & Associates photos)

Figure 18–8a During installation (note size and depth of trench to size of live fascine bundle)

Figure 18–8b Three months after installation

Inert materials—String used for bundling should be untreated twine.

Dead stout stakes used to secure the live fascines should be 2 1/2-foot long, untreated, 2 by 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length. Only new, sound, unused lumber should be used, and any stakes that shatter upon installation should be discarded (fig. 18–9).

Installation

- Prepare the live fascine bundles and live stakes immediately before installation.
- Beginning at the base of the slope, dig a trench on the contour just large enough to contain the live fascine. The trench will vary in width from 12 to 18 inches, depending on the angle of the slope to be treated. The depth will be 6 to 8 inches, depending on the individual bundle's final size.
- Place the live fascine into the trench.
- Drive the dead stout stakes directly through the live fascine every 2 to 3 feet along its length. Extra stakes should be used at connections or bundle overlaps. Leave the top of the stakes flush with the installed bundle.
- Live stakes are generally installed on the downslope side of the bundle. Drive the live stakes below and against the bundle between the previously installed dead stout stakes. The live stakes should protrude 2 to 3 inches above the top of the live fascine. Place moist soil along the sides of the live fascine. The top of the fascine should be slightly visible when the installation is completed (fig. 18–10).

Next, at intervals on contour or at an angle up the face of the bank, repeat the preceding steps to the top of the slope (table 18–3). When possible, place one or two rows over the top of the slope.

Long straw or similar mulching material should be placed between rows on 2.5:1 or flatter slopes, while slopes steeper than 2.5:1 should have jute mesh or similar material placed in addition to the mulch.

Figure 18–9 A dead stout stake

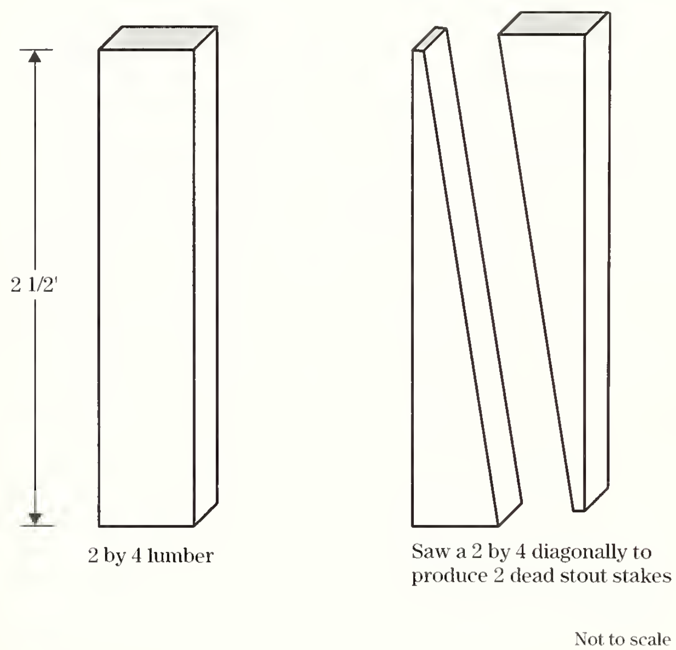
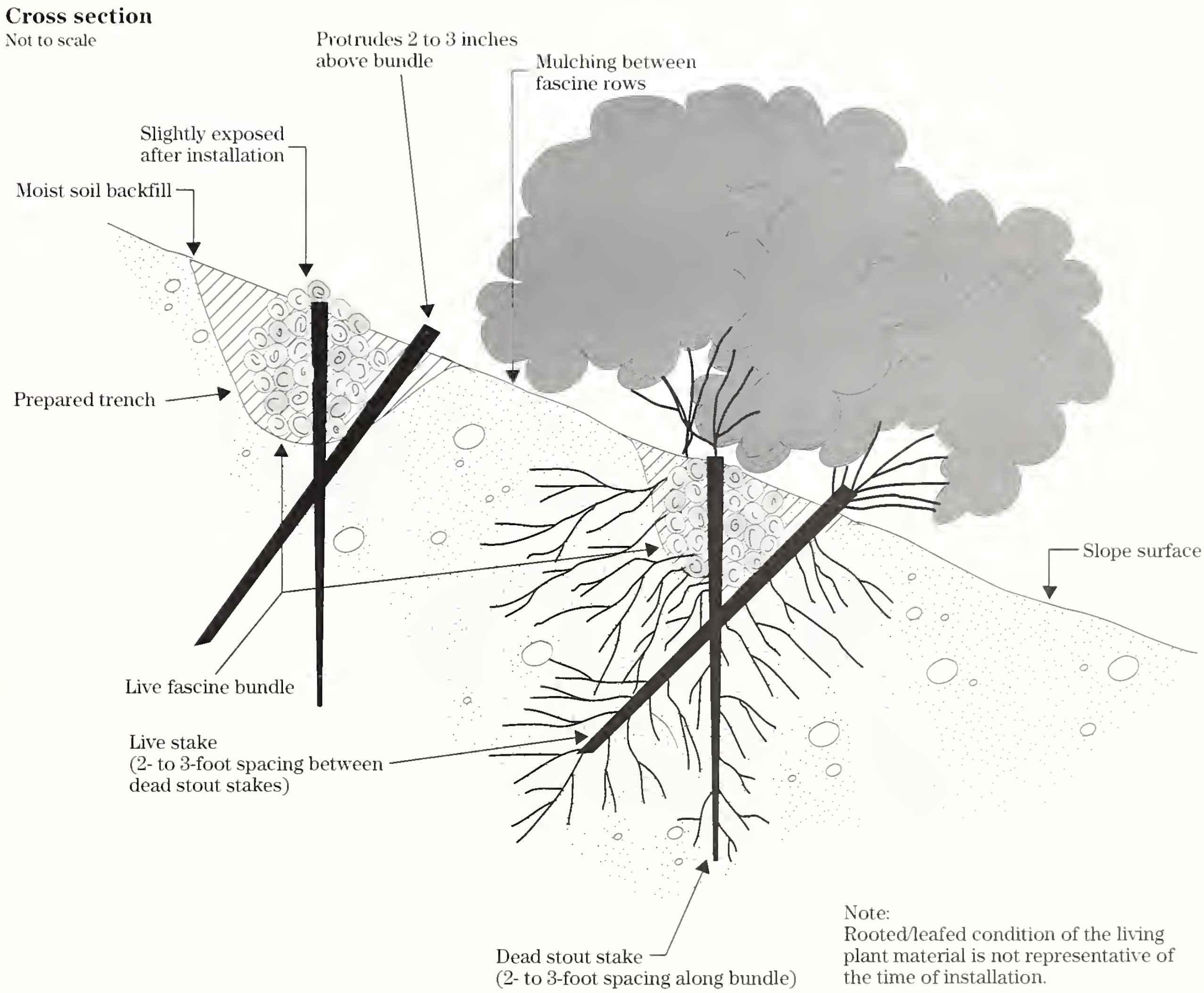
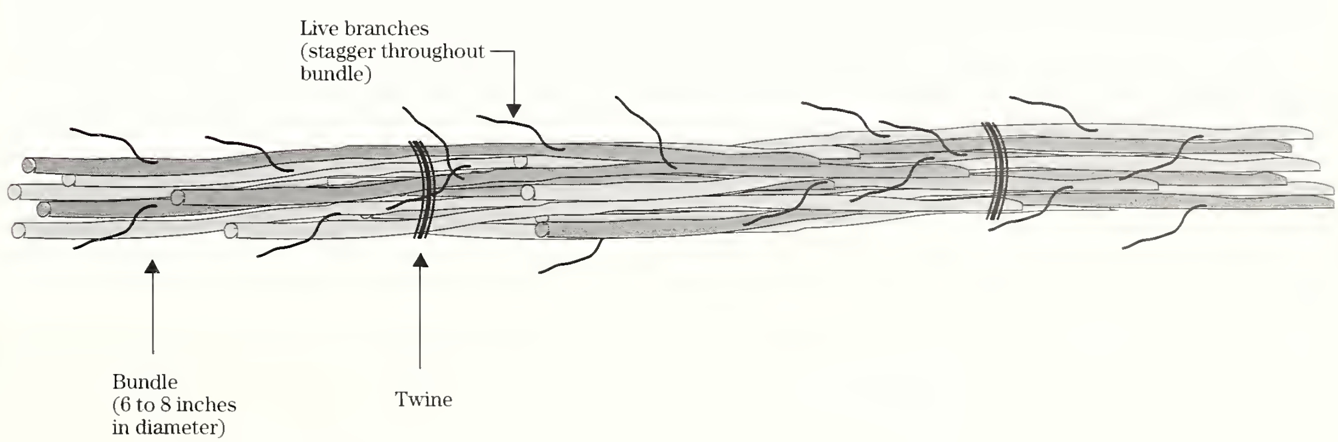


Table 18–3 Live fascine installation guidelines

Slope	Slope distance between trenches (ft)	Maximum slope length (ft)
1:1 to 1.5:1	3 – 4	15
1.5:1 to 2:1	4 – 5	20
2:1 to 2.5:1	5 – 6	30
2.5:1 to 3:1	6 – 8	40
3.5:1 to 4:1	8 – 9	50
4.5:1 to 5:1	9 – 10	60

Figure 18–10 Live fascine details





(3) Brushlayer

(i) Description—Brushlayering is somewhat similar to live fascine systems because both involve the cutting and placement of live branch cuttings on slopes. The two techniques differ principally in the orientation of the branches and the depth to which they are placed in the slope. In brushlayering, the cuttings are oriented more or less perpendicular to the slope contour (fig. 18–11). The perpendicular orientation is more effective from the point of view of earth reinforcement and mass stability of the slope.

Brushlayering consists of placing live branch cuttings in small benches excavated into the slope. The benches can range from 2 to 3 feet wide. These systems are recommended on slopes up to 2:1 in steepness and not to exceed 15 feet in vertical height. Brushlayer branches serve as tensile inclusions or reinforcing units. The portions of the brush that protrude from the slope face assist in retarding runoff and reducing surface erosion.

(ii) Applications and effectiveness—Brushlayers perform several immediate functions in erosion control, earth reinforcement, and mass stability of slopes:

- Breaking up the slope length into a series of shorter slopes separated by rows of brushlayer.
- Reinforcing the soil with the unrooted branch stems.
- Reinforcing the soil as roots develop, adding significant resistance to sliding or shear displacement.
- Providing slope stability and allowing vegetative cover to become established.
- Trapping debris on the slope.
- Aiding infiltration on dry sites.
- Drying excessively wet sites.
- Adjusting the site's microclimate, thus aiding seed germination and natural regeneration.
- Redirecting and mitigating adverse slope seepage by acting as horizontal drains.

(iii) Construction guidelines

Live material sizes—Branch cuttings should be 1/2 to 2 inches in diameter and long enough to reach the back of the bench. Side branches should remain intact for installation.

Installation

- Starting at the toe of the slope, benches should be excavated horizontally, on the contour, or angled slightly down the slope, if needed to aid drainage. The bench should be constructed 2 to 3 feet wide.
- The surface of the bench should be sloped so that the outside edge is higher than the inside (fig. 18–12).
- Live branch cuttings should be placed on the bench in a crisscross or overlapping configuration.
- Branch growing tips should be aligned toward the outside of the bench.
- Backfill is placed on top of the branches and compacted to eliminate air spaces. The brush tips should extend slightly beyond the fill to filter sediment.
- Each lower bench is backfilled with the soil obtained from excavating the bench above.
- Long straw or similar mulching material with seeding should be placed between rows on 3:1 or flatter slopes, while slopes steeper than 3:1 should have jute mesh or similar material placed in addition to the mulch.
- The brushlayer rows should vary from 3 to 5 feet apart, depending upon the slope angle and stability (table 18–4).

Table 18–4 Brushlayer installation guidelines

Slope	Slope distance between benches Wet slopes (ft)	Slope distance between benches Dry slopes (ft)	Maximum slope length (ft)
2:1 to 2.5:1	3	3	15
2.5:1 to 3:1	3	4	15
3.5:1 to 4:1	4	5	20

Figure 18–11 A brushlayer system (Robbin B. Sotir & Associates photos)

Figure 18–11a During installation

Figure 18–11b Two years after installation

Figure 18–12 Installing a brushlayer (Robbin B. Sotir & Associates photos)

Figure 18–12a Bench being prepared for a brushlayer

Figure 18–12b Placing live branch cuttings (Note crisscross configuration)

(4) Branchpacking

(i) Description—Branchpacking consists of alternating layers of live branch cuttings and compacted backfill to repair small localized slumps and holes in slopes (fig. 18–13).

(ii) Applications and effectiveness

- Effective in earth reinforcement and mass stability of small earthen fill sites.
- Produces a filter barrier, reducing erosion and scouring conditions.
- Repairs holes in earthen embankments other than dams where water retention is a function.
- Provides immediate soil reinforcement.

(iii) Construction guidelines

Live material—Live branch cuttings may range from 1/2 inch to 2 inches in diameter. They should be long enough to touch the undisturbed soil at the back of the trench and extend slightly from the rebuilt slope face.

Inert material—Wooden stakes should be 5 to 8 feet long and made from 3- to 4-inch diameter poles or 2 by 4 lumber, depending upon the depth of the particular slump or hole.

Figure 18–13 A branchpacking system being installed (Robbin B. Sotir & Associates photo)

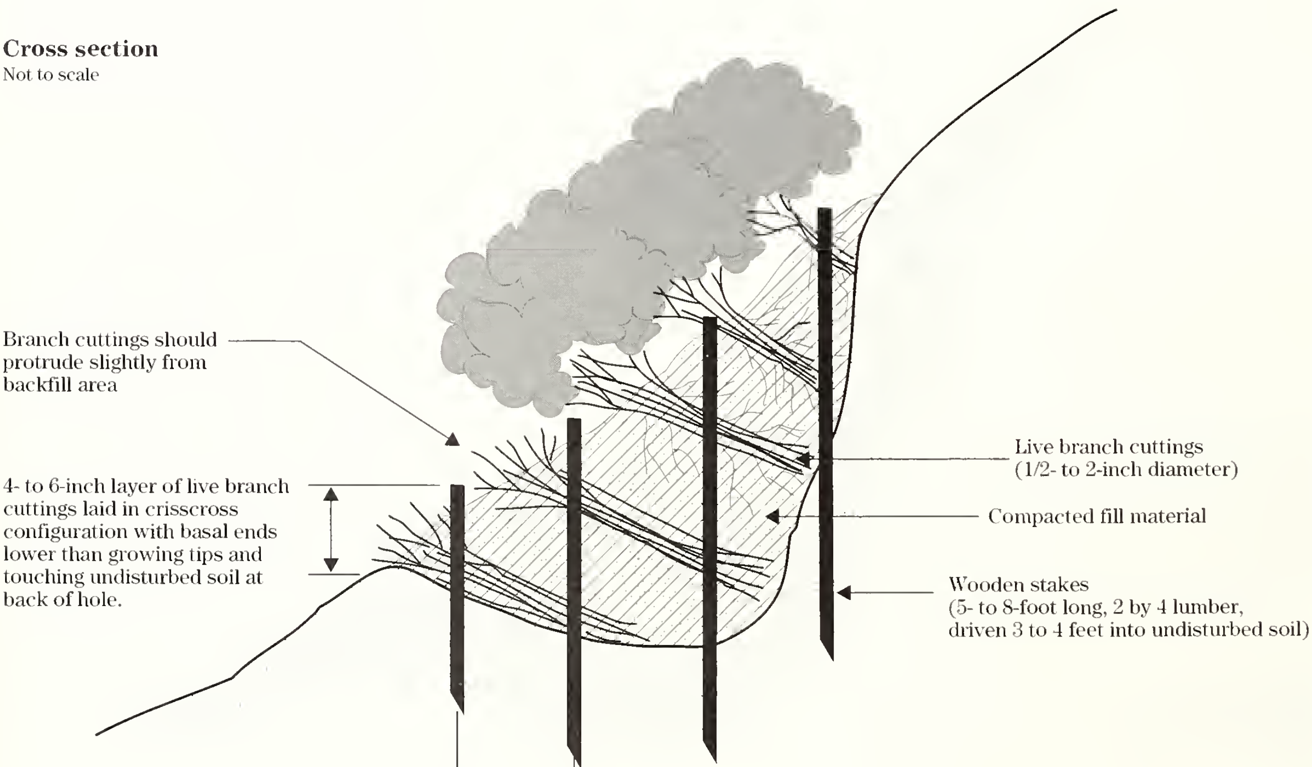
Installation

- Starting at the lowest point, drive the wooden stakes vertically 3 to 4 feet into the ground. Set them 1 to 1 1/2 feet apart.
- A layer of living branches 4 to 6 inches thick is placed in the bottom of the hole, between the vertical stakes, and perpendicular to the slope face (fig 18–14). They should be placed in a crisscross configuration with the growing tips generally oriented toward the slope face. Some of the basal ends of the branches should touch the back of the hole or slope.
- Subsequent layers of branches are installed with the basal ends lower than the growing tips of the branches.
- Each layer of branches must be followed by a layer of compacted soil to ensure soil contact with the branch cuttings.
- The final installation should match the existing slope. Branches should protrude only slightly from the filled face.
- The soil should be moist or moistened to insure that live branches do not dry out.

The live branch cuttings serve as tensile inclusions for reinforcement once installed. As plant tops begin to grow, the branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or holes, while roots spread throughout the backfill and surrounding earth to form a unified mass (fig. 18–15). Branchpacking is not effective in slump areas greater than 4 feet deep or 5 feet wide.

Figure 18–14 Branchpacking details

Cross section
Not to scale



Note:
Rooted leafed condition of the living plant material is not representative of the time of installation.

Figure 18–15 Completed branchpacking system (Robbin B. Sotir & Associates photos)

Figure 18–15a Newly installed system

Figure 18–15b One year after installation

(5) Live gully repair

(i) Description—A live gully repair utilizes alternating layers of live branch cuttings and compacted soil to repair small rills and gullies. Similar to branchpacking, this method is more appropriate for the repair of rills and gullies.

(ii) Applications and effectiveness

- The installed branches offer immediate reinforcement to the compacted soil and reduce the velocity of concentrated flow of water.
- Provides a filter barrier that reduces rill and gully erosion.
- Limited to rills or gullies which are a maximum of 2 feet wide, 1 foot deep, and 15 feet long.

(iii) Construction guidelines

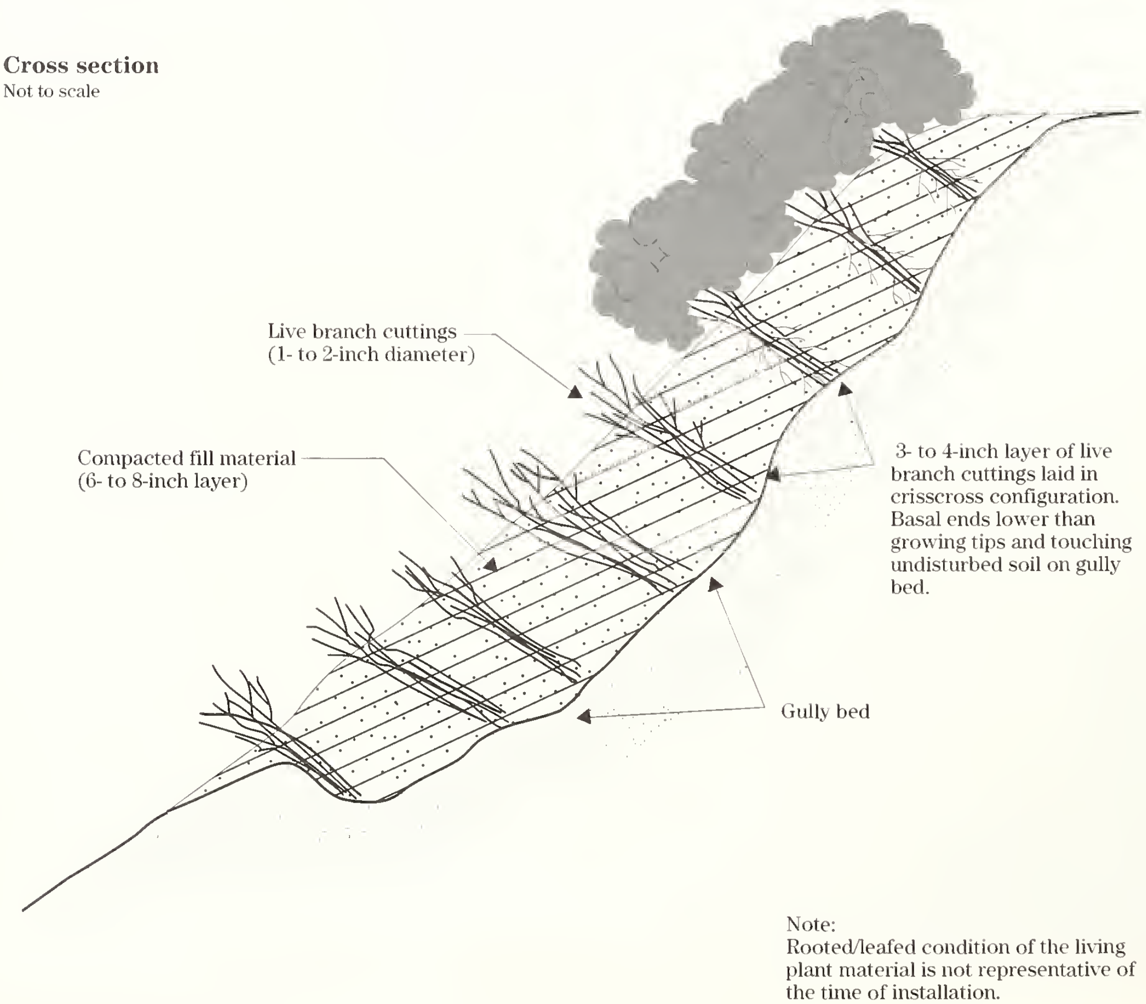
Live material sizes—Live branch cuttings may range from 1/2 inch to 2 inches in diameter. They should be long enough to touch the undisturbed soil at the back of the rill or gully and extend slightly from the rebuilt slope face.

Inert materials—Fill soil is compacted in alternate layers with live branch cuttings.

Installation

- Starting at the lowest point of the slope, place a 3- to 4-inch layer of branches at lowest end of the rill or gully and perpendicular to the slope (fig. 18–16).

Figure 18–16 Live gully repair details



- Cover with a 6- to 8-inch layer of fill soil.
- Install the live branches in a crisscross fashion. Orient the growing tips toward the slope face with basal ends lower than the growing tips.
- Follow each layer of branches with a layer of compacted soil to ensure soil contact with the live branch cuttings.

(6) Live cribwall

(i) Description—A live cribwall consists of a hollow, box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings which root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (fig. 18–17).

(ii) Applications and effectiveness

- This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Not designed for or intended to resist large, lateral earth stresses. It should be constructed to a maximum of 6 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a more vertical structure is required.
- Provides immediate protection from erosion, while established vegetation provides long-term stability.
- Should be tilted back or battered if the system is built on a smooth, evenly sloped surface.
- May also be constructed in a stair-step fashion, with each successive course of timbers set back 6 to 9 inches toward the slope face from the previously installed course.

Figure 18–17 A live cribwall being installed (Robbin B. Sotir & Associates photo)

(iii) Construction guidelines

Live material sizes—Live branch cuttings should be 1/2 to 2 inches in diameter and long enough to reach the back of the wooden crib structure.

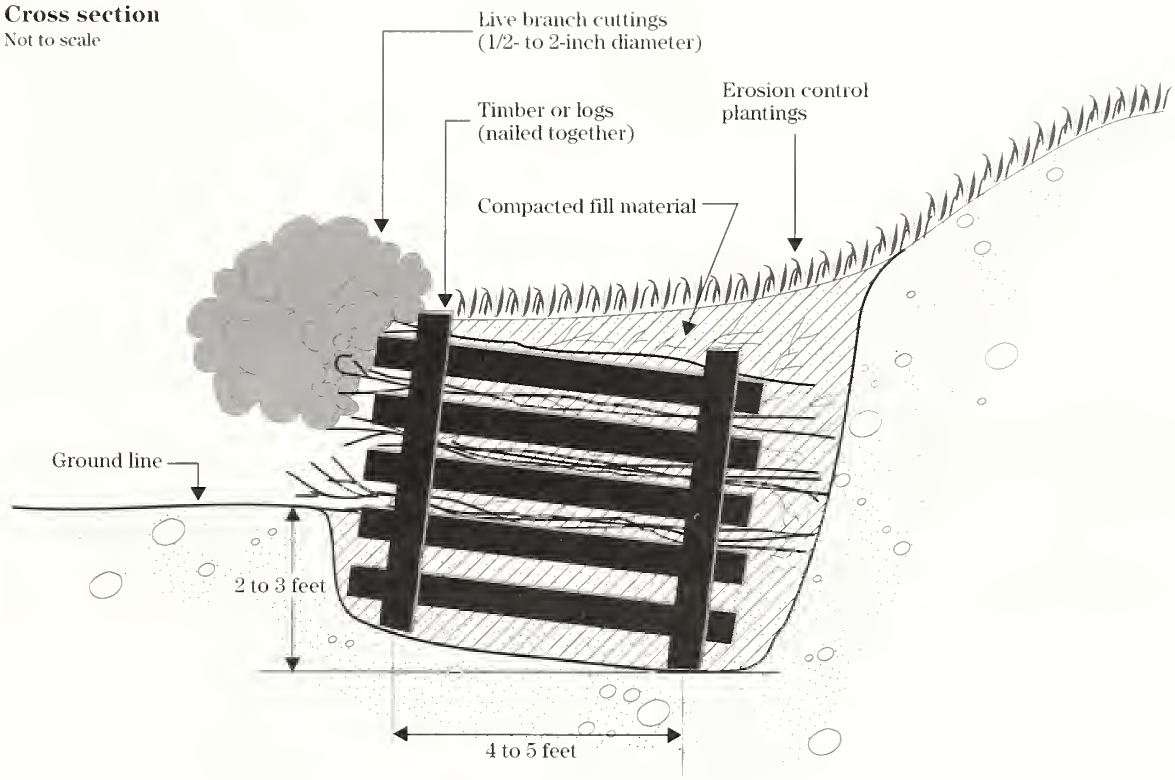
Inert materials—Logs or timbers should range from 4 to 6 inches in diameter or dimension. The lengths will vary with the size of the crib structure.

Large nails or rebar are required to secure the logs or timbers together.

Installation

- Starting at the lowest point of the slope, excavate loose material 2 to 3 feet below the ground elevation until a stable foundation is reached.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.
- Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4 to 5 feet apart and parallel to the slope contour.
- Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course to overhang the front and back of the previous course by 3 to 6 inches.
- Each course of the live cribwall is placed in the same manner and nailed to the preceding course with nails or reinforcement bars.
- When the cribwall structure reaches the existing ground elevation, place live branch cuttings on the backfill perpendicular to the slope; then cover the cuttings with backfill and compact.
- Live branch cuttings should be placed at each course to the top of the cribwall structure with growing tips oriented toward the slope face. Follow each layer of branches with a layer of compacted soil to ensure soil contact with the live branch cuttings. Some of the basal ends of the live branch cuttings should reach to undisturbed soil at the back of the cribwall with growing tips protruding sightly beyond the front of the cribwall (fig. 18–18).

Figure 18–18 Live cribwall details



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

(7) Vegetated rock gabions

(i) Description—Vegetated gabions begin as rectangular containers fabricated from a triple twisted, hexagonal mesh of heavily galvanized steel wire. Empty gabions are placed in position, wired to adjoining gabions, filled with stones and then folded shut and wired at the ends and sides. Live branches are placed on each consecutive layer between the rock-filled baskets. These will take root inside the gabion baskets and in the soil behind the structures. In time the roots consolidate the structure and bind it to the slope (fig. 18–19).

(ii) Applications and effectiveness

- This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Not designed for or intended to resist large, lateral earth stresses. It should be constructed to a maximum of 5 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a more vertical structure is required.

(iii) Construction guidelines

Live material sizes—Branches should range from 1/2 to 1 inch in diameter and must be long enough to reach beyond the back of the rock basket structure into the backfill.

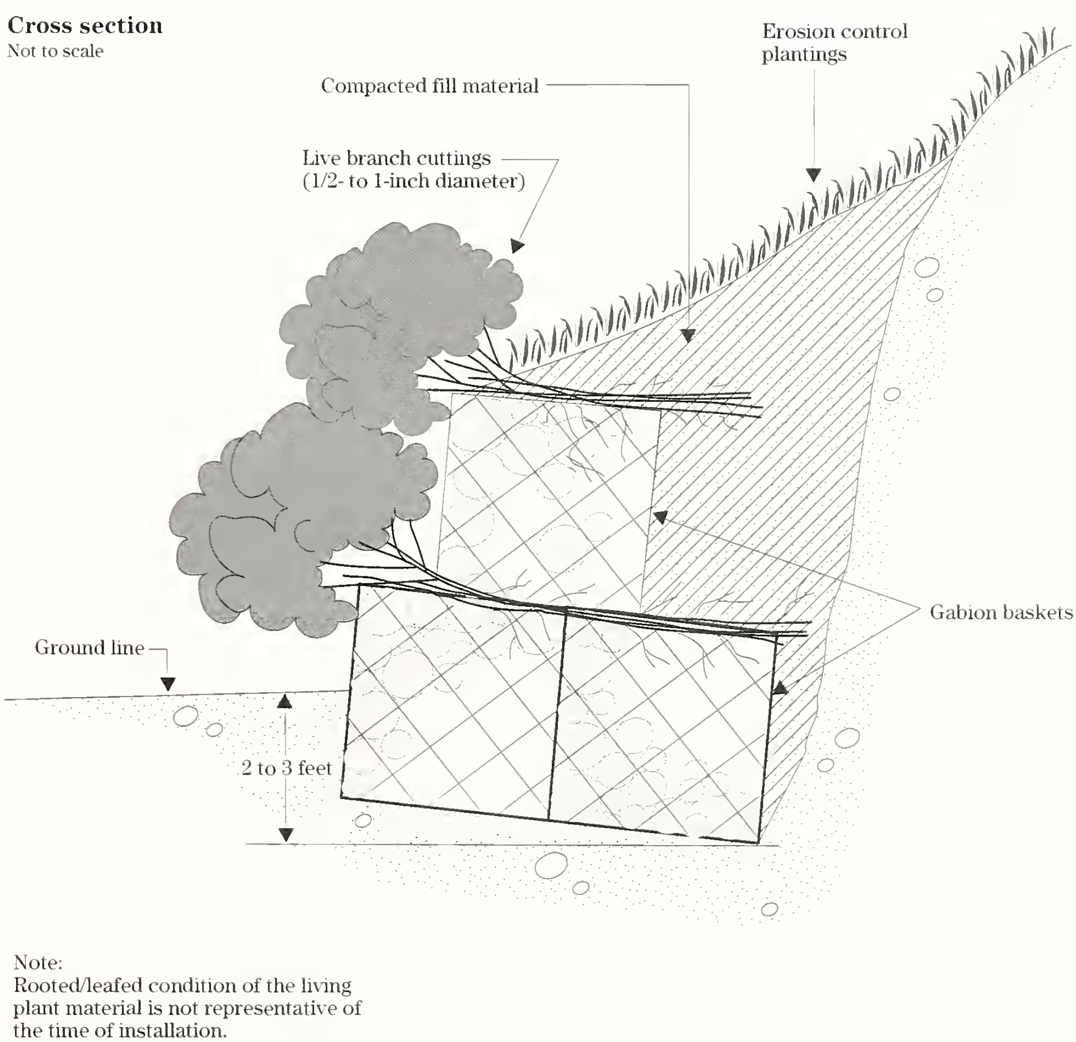
Inert materials—Inert material requirements include wire gabion baskets and rocks to fill the baskets.

Figure 18–19 An established vegetated rock gabion system (Robbin B. Sotir & Associates photo)

Installation

- Starting at the lowest point of the slope, excavate loose material 2 to 3 feet below the ground elevation until a stable foundation is reached.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure. This will provide additional stability to the structure and ensure that the living branches root well.
- Place the fabricated wire baskets in the bottom of the excavation and fill with rock.
- Place backfill between and behind the wire baskets.
- Place live branch cuttings on the wire baskets perpendicular to the slope with the growing tips oriented away from the slope and extending slightly beyond the gabions. The live cuttings must extend beyond the backs of the wire baskets into the fill material. Place soil over the cuttings and compact it.
- Repeat the construction sequence until the structure reaches the required height (fig. 18–20).

Figure 18–20 Vegetated rock gabion details



(8) Vegetated rock wall

(i) Description—A vegetated rock wall is a combination of rock and live branch cuttings used to stabilize and protect the toe of steep slopes. Vegetated rock walls differ from conventional retaining structures in that they are placed against relatively undisturbed earth and are not intended to resist large lateral earth pressures.

(ii) Applications and effectiveness

- This system is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Useful where space is limited and natural rock is available.

(iii) Construction guidelines

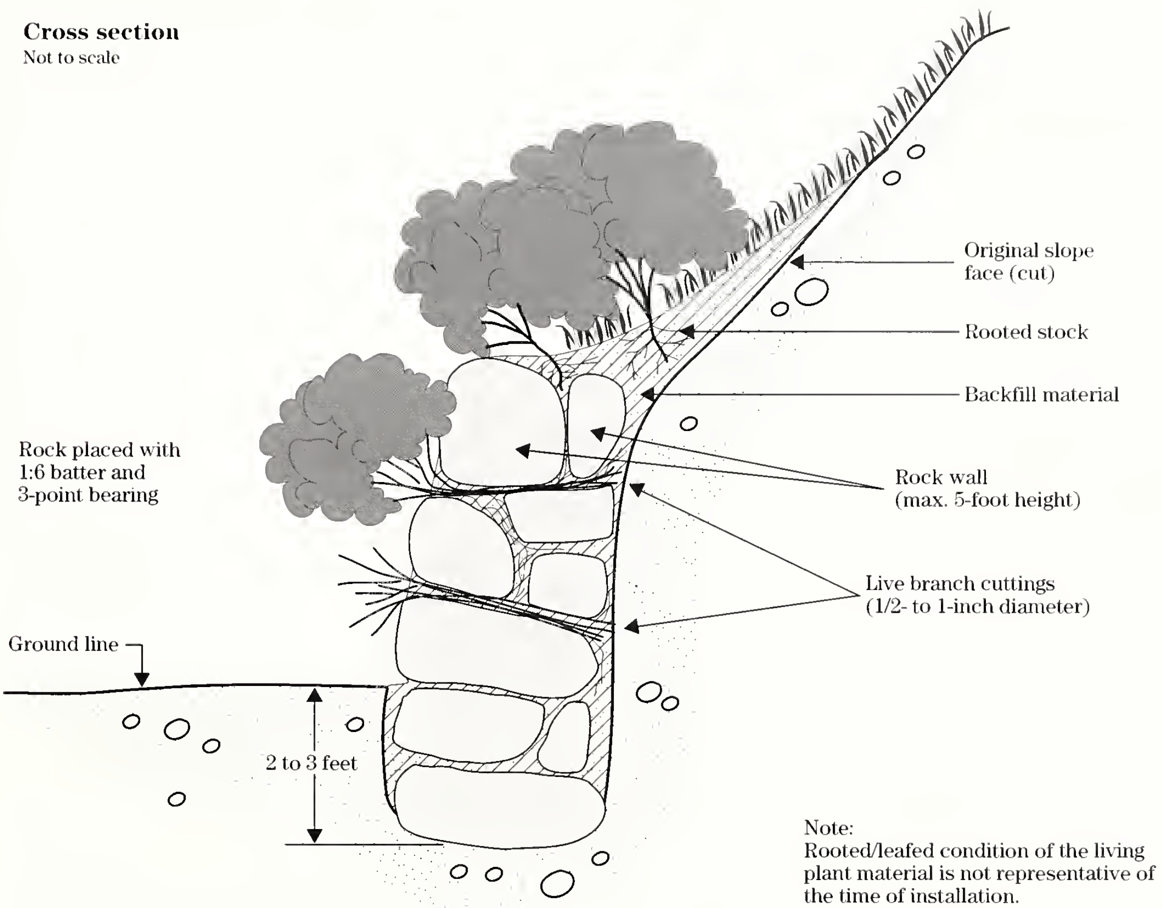
Live material sizes—Live cuttings should have a diameter of 1/2 to 1 inch and be long enough to reach beyond the rock structure into the fill or undisturbed soil behind.

Inert materials—Inert materials consist of rocks and fill material for the wall construction. Rock used should normally range from 8 to 24 inches in diameter. Larger boulders should be used for the base.

Installation

- Starting at the lowest point of the slope, remove loose soil until a stable base is reached. This usually occurs 2 to 3 feet below ground elevation. Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.
- Excavate the minimum amount from the existing slope to provide a suitable recess for the wall.
- Provide a well-drained base in locations subject to deep frost penetration.
- Place rocks with at least a three-point bearing on the foundation material or underlying rock course. They should also be placed so that their center of gravity is as low as possible, with their long axis slanting inward toward the slope if possible.
- When a rock wall is constructed adjacent to an impervious surface, place a drainage system at the back of the foundation and outside toe of the wall to provide an appropriate drainage outlet.
- Overall height of the rock wall, including the footing, should not exceed 5 feet.
- A wall can be constructed with a sloping bench behind it to provide a base on which live branch cuttings can be placed during construction. Live branch cuttings should also be tamped or placed into the openings of the rock wall during or after construction. The butt ends of the branches should extend into the backfill or undisturbed soil behind the wall.
- The live branch cuttings should be oriented perpendicular to the slope contour with growing tips protruding slightly from the finished rock wall face (fig. 18–21).

Figure 18–21 Vegetated rock wall details



(9) Joint planting

(i) Description—Joint planting or vegetated riprap involves tamping live cuttings of rootable plant material into soil between the joints or open spaces in rocks that have previously been placed on a slope (fig. 18–22). Alternatively, the cuttings can be tamped into place at the same time that rock is being placed on the slope face.

(ii) Applications and effectiveness

- Used where rock riprap is required.
- Roots improve drainage by removing soil moisture. Over time, they create a living root mat in the soil base upon which the rock has been placed. The root systems of this mat help to bind or reinforce the soil and to prevent washout of fines between and below the rock units (fig. 18–23).

(iii) Construction guidelines

Live material sizes—The cuttings must have side branches removed and bark intact. They should range in diameter from 1/2 inch to 1 1/2 inches and be sufficiently long to extend into soil below the rock surface.

Installation

- Tamp live branch cuttings into the openings of the rock during or after construction. The butt ends of the branches should extend into the backfill or undisturbed soil behind the riprap.
- Orient the live branch cuttings perpendicular to the slope with growing tips protruding slightly from the finished face of the rock (fig. 18–24).

Figure 18–22 A newly established joint planting stake (Robbin B. Sotir & Associates photo)

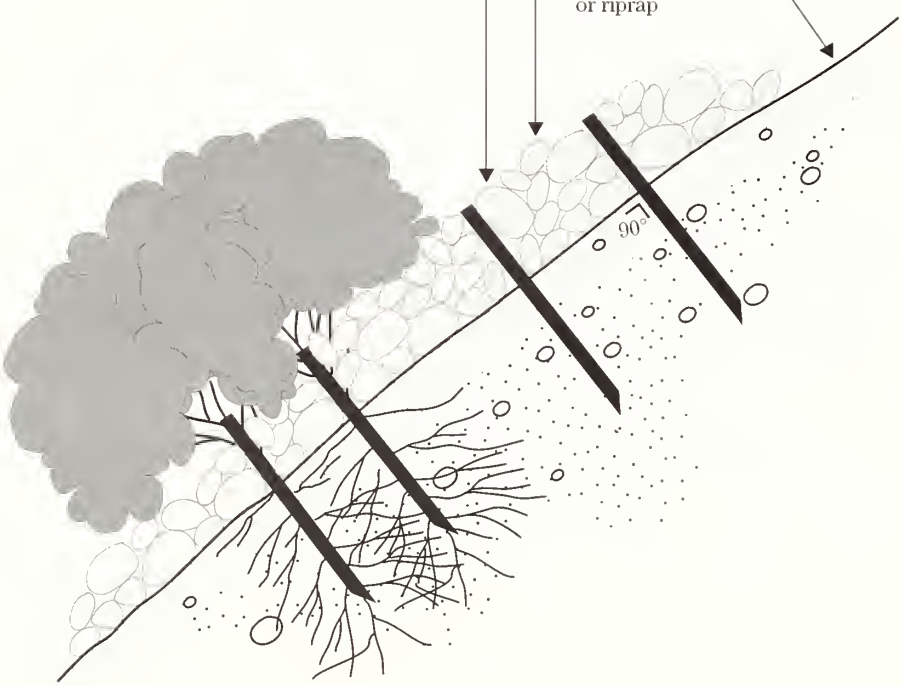
Figure 18–23 Roots improve drainage by removing soil moisture (Robbin B. Sotir & Associates photos)

Figure 18–23a Root system 7 months after installation

Figure 18–23b Joint planted area after a 2 year growth

Figure 18–24 Joint planting details

Cross section
Not to scale



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

(c) Soil bioengineering materials

(1) Locating and selecting plant materials

(i) Commercial sources—Commercially grown plant materials are suitable sources of vegetation for use in soil bioengineering systems; however, it is necessary to allow adequate lead time for their procurement and delivery.

The SCS Plant Materials Program has selected superior cultivars of willows, dogwoods, and other species, which have been evaluated in soil bioengineering systems and are being produced commercially. The most desirable species and cultivars to use can be determined from specifications for critical area stabilization for each state.

The information on plant tolerances in table 18–5 should be used in selecting species appropriate for adverse site conditions. Plant materials specialists are closely involved with the testing of plants and can assist with up-to-date information on cultivar adaptation.

Table 18–5 Plant tolerance

Name	Location	Availability	Tolerance to deposition [1/]	Tolerance to flooding [2/]	Tolerance to drought [3/]	Salt tolerance [4/]
Acer negundo Boxelder	N, NE	Common	High	High	High	Medium
Alnus rubra Red alder	NW	Very common	High	Medium	Low	Low
Baccharis glutinosa Water wally	W	Common	Medium	High	Medium	Low
Baccharis halimifolia Eastern baccharis	S, SE	Common	Medium	High	Medium	Medium
Baccharis pilularis Coyotebrush	W	Very common	Medium	Medium	High	Medium
Baccharis viminea Mule fat	W	Very common	High	High	High	Medium
Betula papyrifera Paper birch	N, E, & W	Common	Medium	Medium	Medium	Medium
Betula pumila Low birch	N, E, & W	Common	Low	---	---	Low
Cornus amomum Silky dogwood	N, SE	Very common	Low	Medium	Medium	Low

See footnotes at end of table.

Table 18–5 Plant tolerance — Continued

Name	Location	Availability	Tolerance to deposition [1/]	Tolerance to flooding [2/]	Tolerance to drought [3/]	Salt tolerance [4/]
Cornus racemosa Gray dogwood	NE	Common	Medium	Medium	High	Low
Cornus rugosa Roundleaf dogwood	NE	Common	– – –	– – –	– – –	– – –
Cornus sericea ssp. stolonifera Red osier dogwood	N, NE, & NW	Very common	Low	High	Medium	Low
Crataegus Sp. Hawthorn	SE	Uncommon	Medium	Low	High	Low
Elaeagnus commutata Silverberry	N. Cent.	Very Common	High	Low	High	Medium
Ligustrum sinense Chinese privet	S, SE	Common	High	Medium	Medium	Low
Lonicera involucrata Black twinberry	E	Common	Medium	Medium	Low	Low
Physocarpus capitatus Pacific ninebark	NW, W	Common	Low	Medium	Low	Low
Physocarpus opulifolius Common ninebark	NE	Common	Low	Medium	Medium	Medium
Populus angustifolia Arrowleaf cottonwood	W	Common	Medium	Medium	High	Medium
Populus balsamifera ssp. trichocarpa Black cottonwood	NW	Common	Medium	Medium	Medium	Medium
Populus deltoides Eastern cottonwood	MW, E	Very common	Medium	High	Medium	Low
Populus fremontii Fremont cottonwood	SW	Very common	Medium	Medium	Medium	Medium

See footnotes at end of table.

Table 18–5 Plant tolerance — Continued

Name	Location	Availability	Tolerance to deposition [1/]	Tolerance to flooding [2/]	Tolerance to drought [3/]	Salt tolerance [4/]
Populus tremuloides Quaking aspen	NW	Very common	Medium	Low	Medium	Medium
Robinia pseudoacacia Black locust	NE	Common	Medium	Low	High	High
Rubus allegheniensis Allegheny blackberry	NE	Very common	Medium	Medium	Medium	Low
Rubus spectabilis Salmonberry	SW, NW	Very common	Medium	Medium	Medium	Low
Rubus strigosus Red raspberry	N, NE, & W	Very common	Medium	Low	Medium	Low
Salix exigua Coyote willow	NW	Fairly common	High	High	Medium	Low
ssp. interior Sandbar willow	N, SE	Common	High	High	Low	High
Salix amygdaloides Peachleaf willow	N, S	Common	High	High	Low	High
Salix bonplandiana Pussy willow	W & MW	Very common	Medium	Medium	Low	– – –
Salix eriocephala ssp. ligulifolia Erect willow	NW	Common	High	High	Medium	Low
Salix gooddingii Goodding willow	SW	Very common	High	Medium	Medium	Low
Salix hookeriana Hooker willow	NW	Common	High	High	Low	Medium
Salix humilis Prairie willow	N, NE	Very common	Medium	Medium	High	Low
Salix lasiolepis Arroya willow	W	Common	High	High	Medium	Low

See footnotes at end of table.

Table 18–5 Plant tolerance — Continued

Name	Location	Availability	Tolerance to deposition [1]	Tolerance to flooding [2]	Tolerance to drought [3]	Salt tolerance [4]
Salix lemmonii Lemmon willow	W	Common	High	High	Medium	Low
Salix lucida Shining willow	N, NE	Very common	Medium	Medium	Medium	Low
ssp. lasiandra Pacific willow	NW	Very common	High	High	Low	Low
Salix lutea Yellow willow	W	Very common	Medium	Medium	Medium	Low
Salix nigra Black willow	N, SE	Very common	High	High	Medium	Medium
Salix purpurea Streamco	N, S, E, & W	Very common	High	High	Medium	Low
Salix scouleriana Scoulers willow	NE	Very common	High	High	Medium	Low
Salix sitchensis Sitka willow	NW	Common	High	Medium	Medium	Low
Salix X cotteti Bankers willow	N, S, E, & W	Uncommon	High	High	Medium	Low
Salix discolor Red willow	N, NE	Very common	High	High	High	Medium
Sambucus cerulea Blueberry elderberry	W	Common	Medium	Medium	Medium	Low
Sambucus canadensis American elderberry	NE, SE	Very common	High	Medium	Medium	Low
Sambucus racemosa Red elderberry	NW	Common	Medium	Low	Medium	Low
ssp. pubens Scarlet elder	NE	Common	Medium	Medium	Medium	Low

See footnotes at end of table.

Table 18–5 Plant tolerance — Continued

Name	Location	Availability	Tolerance to deposition 1/	Tolerance to flooding 2/	Tolerance to drought 3/	Salt tolerance 4/
Spiraea alba Meadowsweet spirea	N, E	Common	Low	Medium	Medium	– – –
Spiraea douglasii Douglas spirea	NW	Common	Medium	Medium	Medium	Low
Spiraea tomentosa Hardhack spirea	NE	Common	Medium	Medium	Medium	Medium
Symphoricarpos albus Snowberry	N, NW, & E	Common	Low	Low	High	High
Viburnum alnifolium Hubbiebush viburnum	NE	Fairly common	– – –	– – –	– – –	– – –
Viburnum dentatum Arrowwood viburnum	E	Common	Medium	Medium	Medium	Low
Viburnum lentago Nannyberry viburnum	S, SE	Fairly common	Medium	Low	Medium	Low

1/ Tolerance to deposition—Regrowth from shallow coverage by soil (stream deposits, soil slips). High, Medium, or Low ability for regrowth.

2/ Tolerance to flooding:
- High—severely damaged after 10 to 30 days of flooding.
- Medium—severely damaged after 6 to 10 days of flooding.
- Low—severely damaged after 1 to 5 days of flooding.

3/ Tolerance to drought—Resistance to drought (relative to native vegetation on similar sites) is High, Medium, or Low.

4/ Salt tolerance—Tolerance (relative to salt tolerant native vegetation on similar sites) is High, Medium, or Low.

(ii) Harvesting indigenous species—Correctly selected indigenous species harvested from existing stands of living woody vegetation are the preferred soil bioengineering materials. The use of indigenous live materials requires careful selection, harvesting, handling, and transporting. They should result in plants that have deep and strong root systems, are relatively inexpensive, are usually effective, and can be installed quickly.

Live plant materials can be cut from existing native or naturalized stands found near the project site or within practical hauling distance. The source site must contain plant species that will propagate easily from cuttings. Cuttings are normally 1/2 to 2 inches in diameter and range in length from 2 to 6 feet.

Chain saws, bush axes, loppers, and pruners are recommended for cutting living plant material. Safety precautions must be followed when using these tools. Onsite plant material should be harvested with great care. In some places a large area can be cut, but other sites require selective cutting. Cuts should be made at a blunt angle, 8 to 10 inches from the ground, to assure that the source sites will regenerate rapidly and in a healthy manner. The harvesting site should be left clean and tidy. Remnant materials that are too large for use in soil bioengineering projects should be chipped or left in piles for wildlife cover. A site may be needed again for future harvesting and should be left in a condition that will enhance its potential for regeneration.

Binding and storage—Live cuttings should be bundled together securely at the collection site for easy loading and handling and for protection during transport. Side branches and brushy limbs should be kept intact.

Transporting—The bundles of live cuttings should be placed on the transport vehicles in an orderly fashion to prevent damage and facilitate handling. They should be covered with a tarpaulin during transportation to prevent drying and additional stress.

Handling—Live cuttings should arrive on the job site within 8 hours of harvest and should be installed immediately. This is especially critical when the ambient temperature is 50 °F or above.

Live cuttings not installed on the day they arrive should be promptly placed in controlled storage conditions and protected until they can be installed. When in storage, the cuttings must receive continuous shade, must be sheltered from the wind, and must be continuously protected from drying by being heeled into moist soils or stored in uncontaminated water. All live cuttings should be removed from storage and used within 2 days of harvest.

(2) Installing plant materials

(i) Timing—Installation of live cuttings should begin concurrently with earth moving operations if they are carried out during the dormant season. All construction operations should be phased together whenever possible. The best time for installation of soil bioengineering systems is during the dormant season, which generally occurs from September to March throughout most of the United States. Each geographic area has a specific dormant season within this broad range, and yearly variations should be taken into account.

(ii) Planting medium—Soil bioengineering projects ideally use onsite stockpiled topsoil as the planting medium of choice. Gravel is not a suitable material for use as fill around live plant materials. Soil bioengineering systems need to be installed in a planting medium that includes fines and organic material and is capable of supporting plant growth. Muddy soils that are otherwise suitable should not be used until they have been dried to a workable moisture content. Heavy clays should be mixed with organic soils to increase porosity. Select soil backfill does not need to be organic topsoil, but it must be able to support plant growth.

Soil samples of the onsite materials should be taken prior to installation of live woody cuttings. Soil samples should also be taken of all fill materials that are brought to the site prior to use. Nutrient testing by an approved laboratory should include analyses for a full range of nutrients, metal contents, and pH. The laboratory reports should also include recommended fertilizer and lime amendments for woody plant materials.

All fill soil around the live vegetative cuttings should be compacted to densities approximating the surrounding natural soil densities. The soil around plants should be free of voids.

(3) Quality control

Maintaining quality control throughout installation and maintenance operations will ensure a successful soil bioengineering project. The following guidelines are recommended:

(i) Pre-construction

- Select plant species for conformance to requirements.
- Locate and secure source sites for harvesting live cuttings or commercial procurement.
- Define construction work area limits.
- Fence off sites requiring special protection.
- Complete and inspect the following preparations:
  - — Layout
  - — Excavation, systems excavation
  - — Bench size, shape, angle
  - — Preparation of site; i.e., clearing, grading, and shaping
  - — Disposal of excess gravel, soil, and debris
  - — Depth of excavation
  - — Vegetation to be removed/preserved
  - — Stockpiling of suitable soil and/or rock

(ii) Construction

- Inspect each system component, at every stage, for the following:
  - — Angle of placement and orientation of the live cuttings
  - — Backfill material/rock and stone material
  - — Fertilizer, method and quantity applied
  - — Lime, method and quantity applied
  - — Preparation of trenches or benches in cut and fill slopes
  - — Staking
  - — Pruning
  - — Stock handling and preparation
  - — Soil compaction
  - — Watering
- Ensure that proper maintenance occurs during and after installation.
- Inspect daily for quality control.
  - — Check all cuttings; remove unacceptable material and use fresh stock for replacement installations.
  - — Continuously check all items in the preconstruction and construction inspection lists.
  - — Inspect the plant materials storage area when it is in use.

(4) Establishment period

(i) Interim inspections—Inspections should be made after the soil bioengineering measures have been installed. The following schedule is recommended:

- Inspect biweekly for the first 2 months. Inspections should note insect infestations, soil moisture, and other conditions that could lead to poor survivability. Immediate action, such as the application of supplemental water, should be taken if conditions warrant.
- Inspect monthly for the next 6 months. Systems not in acceptable growing condition should be noted and, as soon as seasonal conditions permit, should be removed from the site and replaced with materials of the same species and sizes as originally specified.
- Needed reestablishment work should be performed every 6 months during the initial 2-year establishment period. This will usually consist of replacing dead material.
- Extra inspections should always be made during periods of drought or heavy rains. Damaged sections should always be repaired immediately.

(ii) Final inspection—A final inspection should be held 2 years after installation is completed. Healthy growing conditions should exist.

- Healthy growing conditions in all areas refer to overall leaf development and rooted stems defined as follows:

  Live stakes ------------------70%-100% growing
  Live fascines ---------------20%-50% growing
  Live cribwall ---------------30%-60% growing
  Brushlayers -----------------40%-70% growing
  Branchpacking -------------40%-70% growing
  Live gully repair -----------30%-50% growing
  Vegetated rock wall ------50%-80% growing
  Vegetated gabion----------40%-60% growing
  Joint planting --------------50%-70% growing
- Growth should be continuous with no open spaces greater than 2 feet in linear systems. Spaces 2 feet or less will fill in without hampering the integrity of the installed living system.

(5) Maintaining the system

After inspection and acceptance of the established system, maintenance requirements should be minor under normal conditions. Maintenance generally

consists of light pruning and removal of undesirable vegetation. Heavy pruning may be required to reduce competition for light or stimulate new growth in the project plantings. In many situations, installed soil bioengineering systems become source sites for future harvesting operations. The selective removal of vegetation may be required to eliminate undesirable invading species that should be cut out every 3 to 7 years.

More intensive maintenance will sometimes be required to repair problem areas created by high intensity storms or other unusual conditions. Site washouts should be repaired immediately. Generally, reestablishment should take place for a 1-year period following construction completion and consist of the following practices:

- Replacement of branches in dead unrooted sections
- Soil refilling, branchpacking, and compacting in rills and gullies
- Insect and disease control
- Weed control

Gullies, rills, or damaged sections should be repaired through the use of healthy, live branch cuttings preferably installed during the dormant season. The repair should use the branchpacking system for large breaks and the live gully repair system for breaks up to 2 feet wide and 2 feet deep. If the dormant season has passed, the use of rooted stock may be considered.

(d) Vegetated structures

Vegetated structures consist of either low walls or revetments (concrete or rock and mortar) at the foot of a slope with plantings on the interposed benches. A structure at the foot of a slope protects the slope against undermining or scouring and provides a slight buttressing effect. In the case of low walls, it allows regrading of the slope face to a more stable angle without excessive retreat at the crest. Vegetation planted on the crest of the wall and the face of the slope protects against erosion and shallow sloughing. In the case of tiered structures, the roots of woody plants grow into the soil and backfill within the structure, binding them together. The foliage in front covers the structure and enhances its appearance.

These systems are not soil bioengineering structures, as their plant materials represent little or no reinforcement value to the structure.

(1) Low wall/slope face plantings

(i) Description—A low retaining structure at the foot of a slope makes it possible to flatten the slope and establish vegetation. Vegetation on the face of the slope protects against both surface erosion and shallow face sliding (fig. 18–25).

(ii) Materials and installation—Several basic types of retaining structures can be employed as low walls. The simplest type is a gravity wall that resists lateral earth pressures by its weight or mass. The following types of retaining structures can be classified as gravity walls:

- Masonry and concrete walls
- Crib and bin walls
- Cantilever and counterfort walls
- Reinforced earth and geogrid walls

In addition, each of these can be modified in a variety of ways to fit nearly any condition or requirement. A low wall with vegetated slope is shown in figure 18–26. For further discussion of standard engineering design requirements and specifications see National Engineering Handbook, section 6.

Figure 18–25 A low wall with plantings above

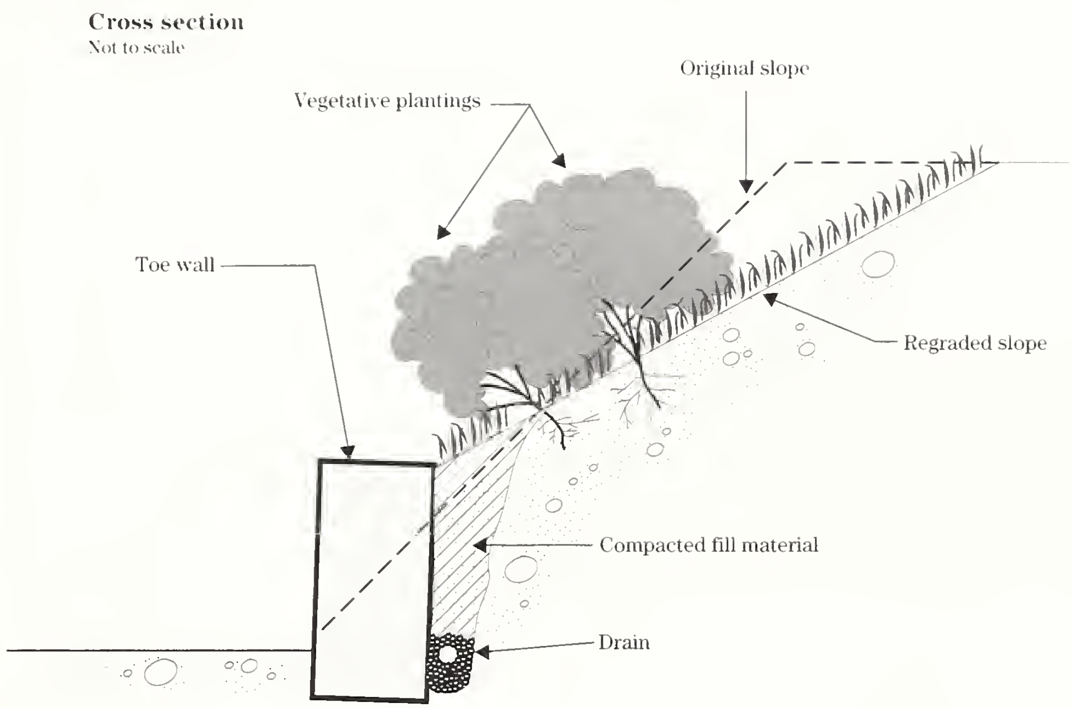


Figure 18–26 Low wall at the base of a slope with vegetation on face of slope (Robbin B. Sotir & Associates photo)

(2) Tiered wall/bench plantings

(i) Description—An alternative to a low wall with face planting is a tiered retaining wall system. This alternative effectively allows vegetation to be planted on slopes that would otherwise be too steep. Shrubs and trees planted on the benches screen the structure behind and lend a more natural appearance while their roots permeate and protect the benches.

Virtually any type of retaining structure can be used in a tiered wall system. A tiered wall system provides numerous opportunities for adding vegetative values on steep slopes and embankments (fig. 18–27).

(3) Cribwalls with plantings

(i) Description—A cribwall is a structure formed by joining a number of cells together and filling them with soil, gravel, or rock to furnish strength and weight. In crib structures, the members are essentially assembled "log cabin" fashion. The frontal, horizontal members are termed stretchers; the lateral members, headers.

The frontal spaces between the stretchers in conventional cribwalls provide openings through which vegetative cuttings can be inserted and established in the crib fill (fig. 18–28).

Figure 18–27 A tiered wall with bench plantings (Robbin B. Sotir & Associates photo)

Figure 18–28 Cribwall systems with face plantings (Robbin B. Sotir & Associates photos)

Figure 18–28a Tiered cribwall system with trees and shrubs planted on benches

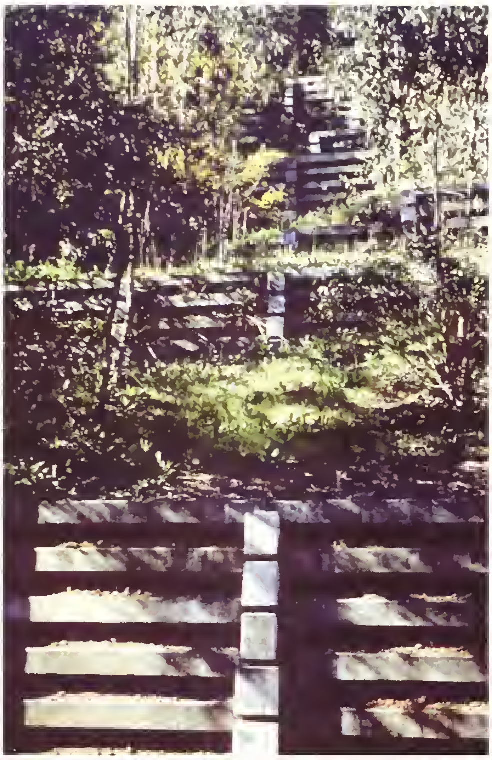


Figure 18–28b Open-front concrete cribwall with plantings in openings

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Glossary

Batter The angle of the front face of a retaining structure with respect to a vertical plane.

Bench A horizontal surface or step in a slope.

Buttressing Lateral restraint provided by earth or rock masses and embedded structural columns, such as piles and well-rooted tree trunks.

Brushlayer Live branch cuttings laid in crisscross fashion on benches between successive lifts of soil.

Concrete cribwall A hollow, structural wall formed out of perpendicular and interlocking concrete beams.

Cut face The open, steep face of an excavated slope.

Cutting A branch or stem pruned from a living plant.

Crib structure A hollow structure constructed of mutually perpendicular, interlocking beams or elements.

Dead stout stake A 2 by 4 timber that has been cut into a specific shape and length.

Face planting Planting live cuttings and other vegetation in the frontal openings of retaining structures.

Gabion A wire mesh basket filled with rock that can be used in multiples as a structural unit.

Grade stabilization The maintenance of a gentle, noneroding gradient on a watercourse or land surface. This is usually accomplished by means of structural measures or by regrading (lengthening) the slope.

Gravity retaining walls Retaining structures that resist lateral earth forces and overturning primarily by their weight.

Grid wall A lattice or grid-like array of timbers that are fastened or anchored to a slope. The grid spaces are filled with topsoil and then seeded or planted.

Joint planting The insertion of live branch cuttings between openings or interstices of rocks, blocks, or other inert armor units and into the natural ground.

Lateral earth pressure The horizontal pressure exerted by soil against a retaining structure.

Live cribwall A hollow, structural wall formed out of mutually perpendicular and interlocking members, usually timber, in which live cuttings are inserted through the front face of the wall into the crib fill and/or natural soil behind the wall.

Live branch cuttings Living, freshly cut branches of woody shrub and tree species that propagate from cuttings embedded in the soil.

Live fascines Bound, elongated sausage-like bundles of live cut branches that are placed in shallow trenches, partly covered with soil, and staked in place to arrest erosion and shallow mass wasting.

Live stake Cuttings from living branches that are tamped or inserted into the earth. The stakes eventually root and leaf out.

Mass movement The movement of large, relatively intact masses of earth and/or rock along a well defined shearing surface as a result of gravity and seepage.

Mass wasting See “Mass movement.”

Reinforced earth Strengthening of a soil fill by utilizing tensile inclusions, such as metal strips, woody fibers, wire mesh, or fabric.

Shallow mass movement Near-surface sliding or movement of earth and/or rock masses usually along planar failure surfaces parallel to the slope face.

Slope flattening Reduction in slope angle by excavation and regrading in order to achieve a more stable slope.

Soil arching Restraint of soil movement through an opening or gap as a result of transfer of shear stress from the deforming (or moving) soil mass to adjacent stationary (nonyielding) portions of the soil.

Soil bioengineering Use of live, woody vegetative cuttings to repair slope failures and increase slope stability. The cuttings serve as primary structural components, drains, and barriers to earth movement.

Steel bin wall Hollow wall sections constructed of steel that are bolted together and filled with rock or gravel to serve as a gravity retaining wall.

Stepped-back reinforced wall A reinforced earth retaining wall in which successively higher portions of the wall are set back from the front in stepped fashion.

Surface armoring Placement of an armor layer, composed of rock, brush matting, gabion mattresses, stabilized earth, etc., on the ground surface.

Tiered retaining wall structures Retaining structures in which successively higher portions of the structure are set back from the front in stepped fashion. Crib, gabion, and reinforced earth walls can be erected in this fashion.

Toe wall A low, structural wall erected at the toe or base of a slope to provide support and protect against undermining.

Undermining The removal of lateral support at the base of a slope by scour, piping erosion, or excavation.

Vegetative cuttings Live, cut stems and branches of plants that will root when embedded or inserted in the ground.

Vegetated earth buttress An earthen mass placed against the base or toe of the slope to improve stability. Vegetation can be planted on the face of the buttress or introduced into the buttress in the form of brushlayers.

Vegetative measures The use of live cuttings, seeding, sodding, and transplanting in order to establish vegetation for erosion control and slope protection work.

Vegetated rock gabions See "Vegetated structures."

Vegetated rock walls See "Vegetated structures."

Vegetated structures A retaining structure in which living plant materials, cuttings, or transplants have been integrated into the structure.

Vegetated structural revetments Porous revetments, e.g., a gabion mattress or riprap, into which live plants or cuttings can be placed or inserted.

Identifying Problems
Achieving Stability

Problems:
- Physical, Hydraulic, Chemical
- Landowner constraints

Morphology: forms and structures

<u>Rosgen</u> - seven major stream types (A-G)
- six additional sub-types (1-6)

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22:169-199.

Purpose(s) - management [engineering, fish habitat, water resources management, etc.]

Concepts:

8 major variables: channel width, depth, velocity, discharge, channel slope, roughness, sediment load, sediment size

Four "levels" of detail:

1. Geomorphic
2. Morphological
3. Stream "state" or condition
4. Verification

1. Geomorphic (geologic forms & structures)
   Purpose: broad characterization
   slope - 9 variations
   - stability noted for some forms.

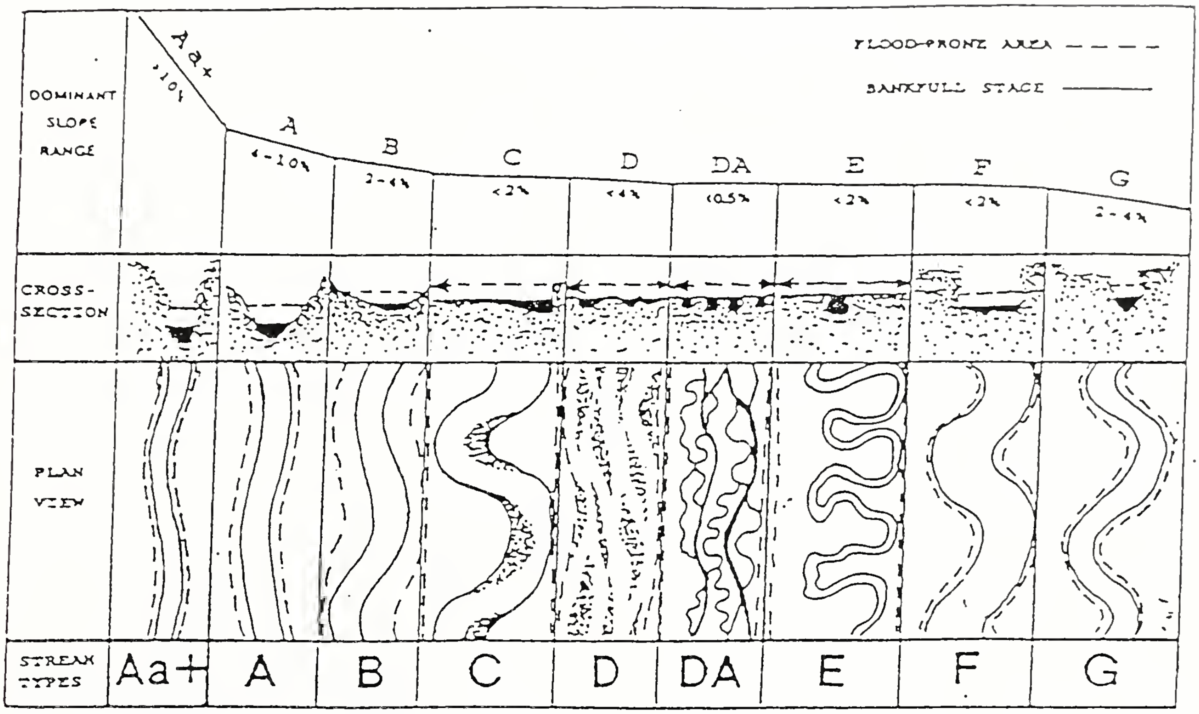
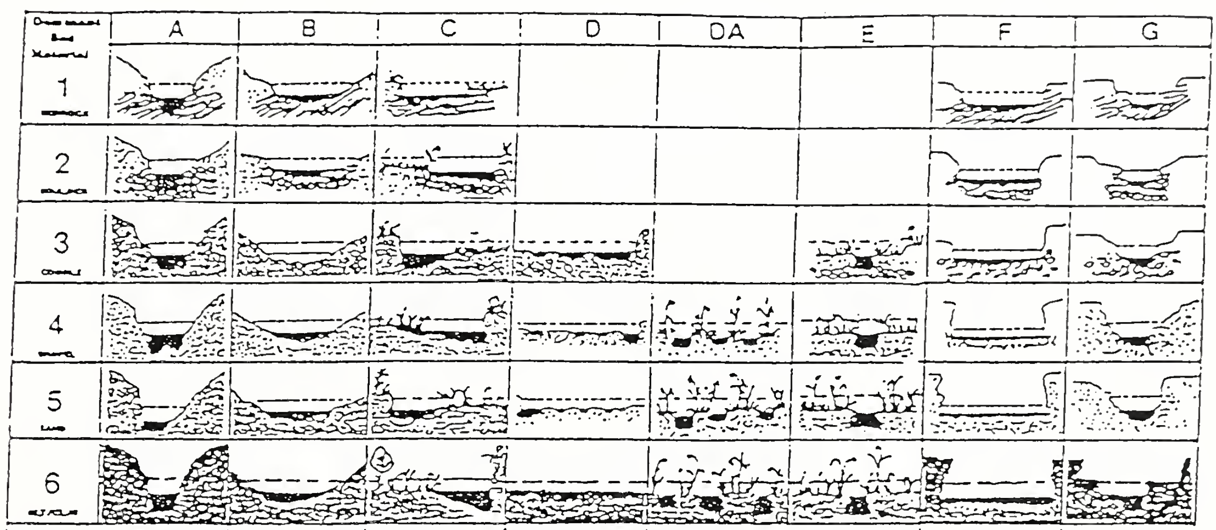


Fig. 1. Longitudinal, cross-sectional and plan views of major stream types.

2. Morphological (non-geologic forms & structures)
   - bed material
   - entrenchment
   - sinuosity
   - w/d ratio

Bed material - crude particle diameter

1. Bedrock	3. Cobble	5. Sand
2. Boulder	4. Gravel	6. Silt/clay



	A	B	C	D	DA	E	F	G
ENTRH	<1.4	1.4-2.2	>2.2	N/A	>2.2	>2.2	<1.4	<1.4
SIN	<1.2	>1.2	>1.4	<1.1	1.1-1.6	>1.5	>1.4	>1.2
W/D	<12	>12	>12	>40	<40	<12	>12	<12
SLOPE	.04-.099	.02-.039	<.02	<.02	<.005	<.02	<.02	.02-.039

Fig. 4. Illustrative guide showing cross-sectional configuration, composition and delineative criteria of major stream types.

Entrenchment - Deeply incised?
- Vertical containment of stream

Entrenchment ratio = F/B = R_E

Entrenched	$1.0 \geq R_E \geq 1.4$
Moderately entrenched	$1.4 > R_E \geq 2.2$
Slightly entrenched	$R_E > 2.2$

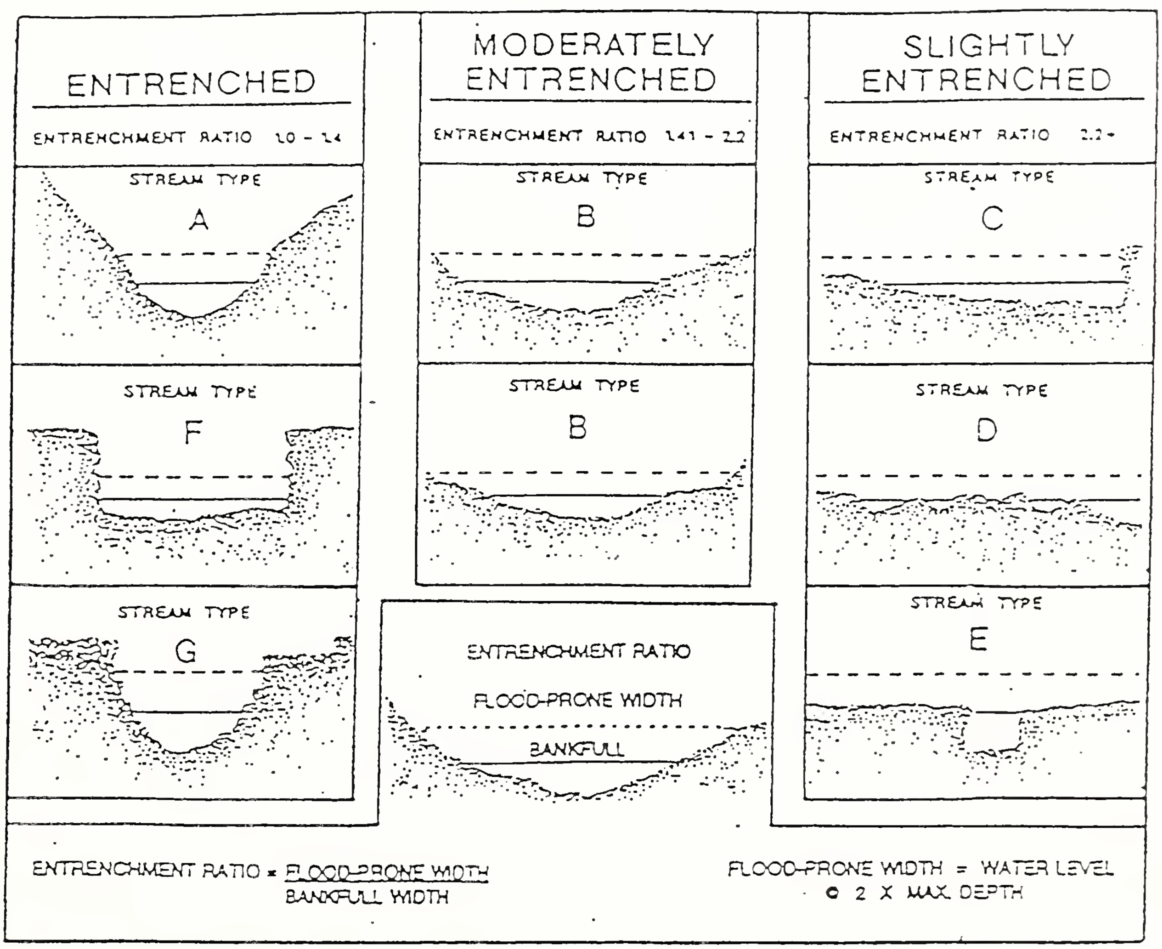


Fig. 6. Examples and calculations of channel entrenchment.

Width/depth ratio

$$W/D = \frac{\text{Bank Full Width}}{\text{Bank Full Mean Depth}}$$

Low W/D $\leq$ 12
Moderate to high W/D >12

$$\text{Sinuousity Ratio} = \frac{\text{Stream Length}}{\text{Valley Length}}$$

Obviously not much information for short reaches.

Use Table 3 to determine if area is suitable for Riparian Planting - If I plant it, will it last?

Table 3
Management interpretations of various stream types

Stream type	Sensitivity to disturbance [a]	Recovery potential [b]	Sediment supply [c]	Streambank erosion potential	Vegetation controlling influence [d]
A1	very low	excellent	very low	very low	negligible
A2	very low	excellent	very low	very low	negligible
A3	very high	very poor	very high	high	negligible
A4	extreme	very poor	very high	very high	negligible
A5	extreme	very poor	very high	very high	negligible
A6	high	poor	high	high	negligible
B1	very low	excellent	very low	very low	negligible
B2	very low	excellent	very low	very low	negligible
B3	low	excellent	low	low	moderate
B4	moderate	excellent	moderate	low	moderate
B5	moderate	excellent	moderate	moderate	moderate
B6	moderate	excellent	moderate	low	moderate
C1	low	very good	very low	low	moderate
C2	low	very good	low	low	moderate
C3	moderate	good	moderate	moderate	very high
C4	very high	good	high	very high	very high
C5	very high	fair	very high	very high	very high
C6	very high	good	high	high	very high
D3	very high	poor	very high	very high	moderate
D4	very high	poor	very high	very high	moderate
D5	very high	poor	very high	very high	moderate
D6	high	poor	high	high	moderate
DA4	moderate	good	very low	low	very high
DA5	moderate	good	low	low	very high
DA6	moderate	good	very low	very low	very high
E3	high	good	low	moderate	very high
E4	very high	good	moderate	high	very high
E5	very high	good	moderate	high	very high
E6	very high	good	low	moderate	very high
F1	low	fair	low	moderate	low
F2	low	fair	moderate	moderate	low
F3	moderate	poor	very high	very high	moderate
F4	extreme	poor	very high	very high	moderate
F5	very high	poor	very high	very high	moderate
F6	very high	fair	high	very high	moderate
G1	low	good	low	low	low
G2	moderate	fair	moderate	moderate	low
G3	very high	poor	very high	very high	high
G4	extreme	very poor	very high	very high	high
G5	extreme	very poor	very high	very high	high
G6	very high	poor	high	high	high

[a] Includes increases in streamflow magnitude and timing and/or sediment increases.
[b] Assumes natural recovery once cause of instability is corrected.
[c] Includes suspended and bedload from channel derived sources and/or from stream adjacent slopes.
[d] Vegetation that influences width/depth ratio-stability.

Conservation Structures - purpose - stabilize some erosive or potentially erosive channels.

Principles

Reduce channel gradient e.g. velocities are non-erosive
keep v above minimum (velocities above deposition level)

silting velocity < v < erosive velocity

Classifications

Temporary	Permanent
low labor costs	SCS, Bureau of Reclamation
low material cost	will provide design specs
5 out of 50 worked	on request
Materials: logs	Materials: concrete
sod	rebar
wire	earth
earth	

Functional Requirements

1. Sufficient capacity to pass the design discharge.
2. Dissipate kinetic energy of flow within the structure
3. Affects on conditions upstream (e.g. ponding, etc.) must be acceptable

Needs for construction

1. Firm foundation
2. Dry foundation - drain artificially if necessary
3. Remove organic material - improve bond between structure and soil

Functions

1. Provides passage under an embankment (culvert)
2. Lowers water through a drop when used with a riser (vertical segment of pipe) and/or drop inlet

Structures	Flow Type
Drop Spillway	Weir flow
Chutes and Flumes	Weir flow
Pipe Spillways	Pipe flow, Orifice flow
Drop inlet Pipe Spillway	Orifice flow, Pipe flow
Culverts	Pipe, Orifice flow

Weirs - overfall that forces flow through critical flow,
used for gages,
used for part of inlet structures

Sharp crested weir

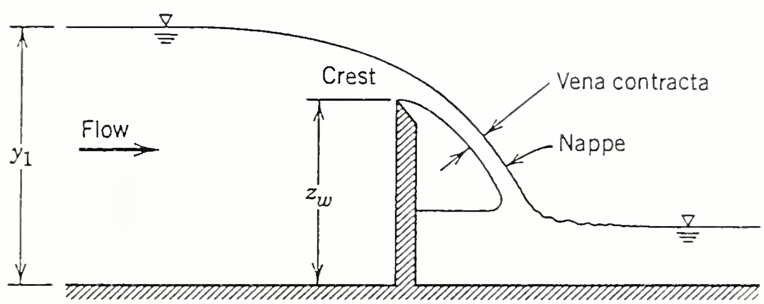


Fig. 10.14 Section view of flow over a sharp-crested weir.

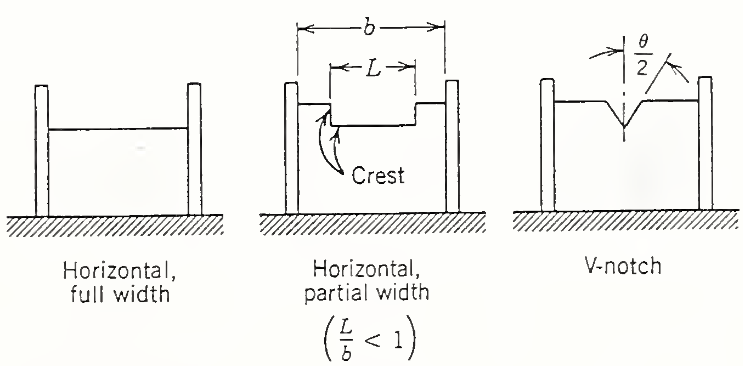


Fig. 10.15 Principal types of sharp-crested weirs.

Broad crested weir

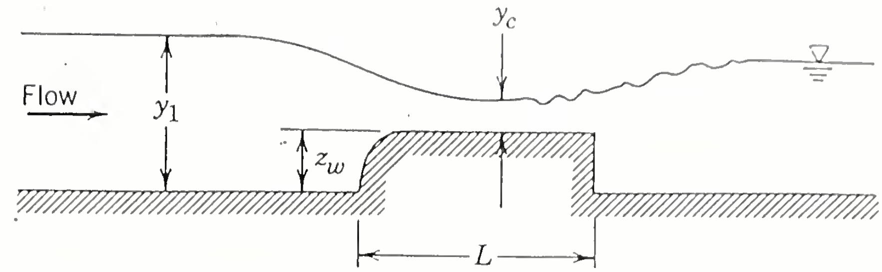


Fig. 10.17 Flow over a broad-crested weir.

Drop inlet structures

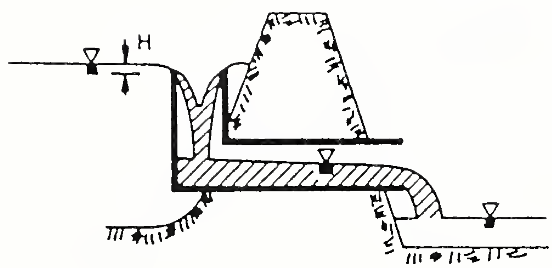
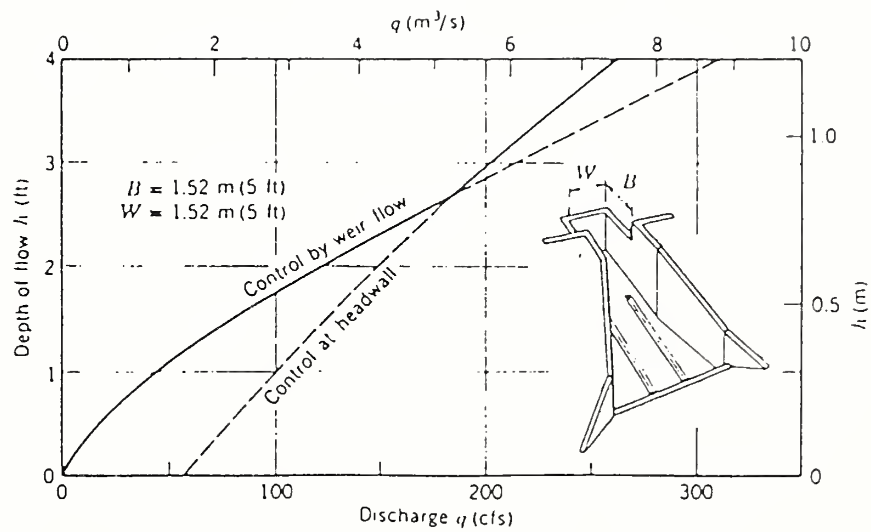
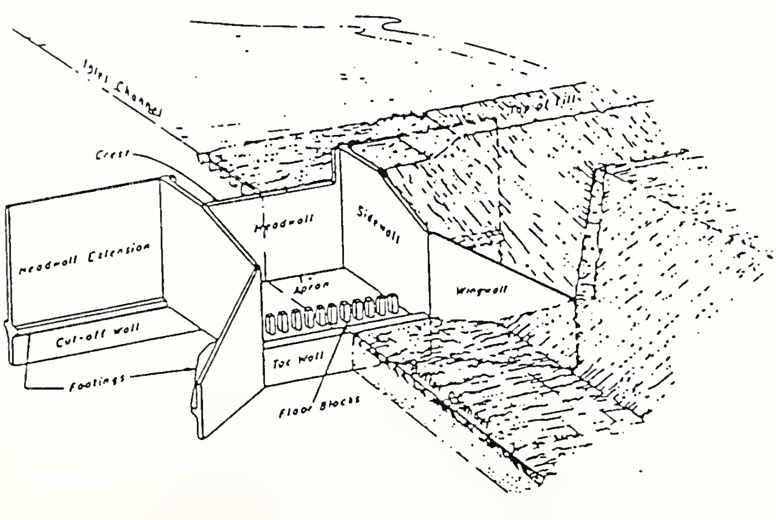


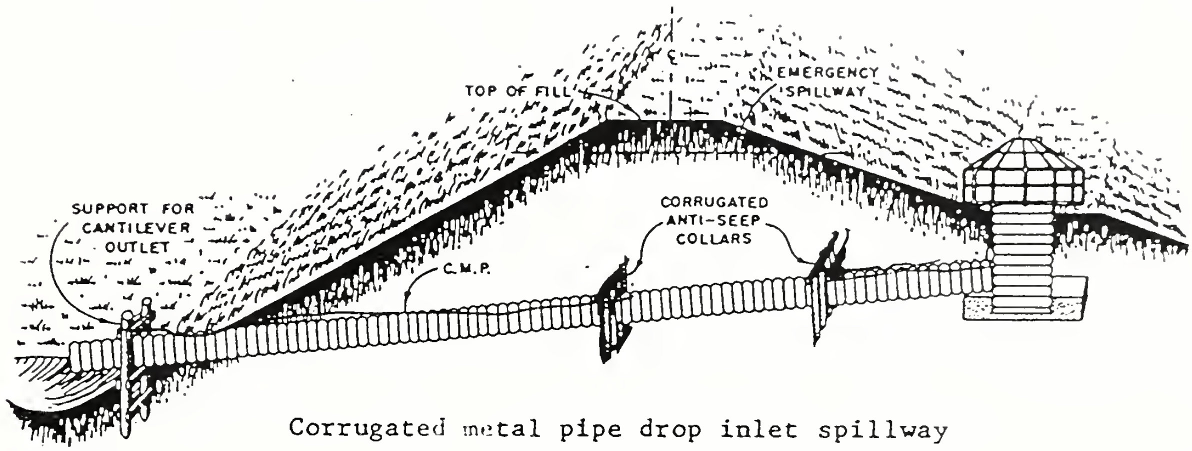
Figure 4.4a. Illustration of weir control on a drop inlet spillway.



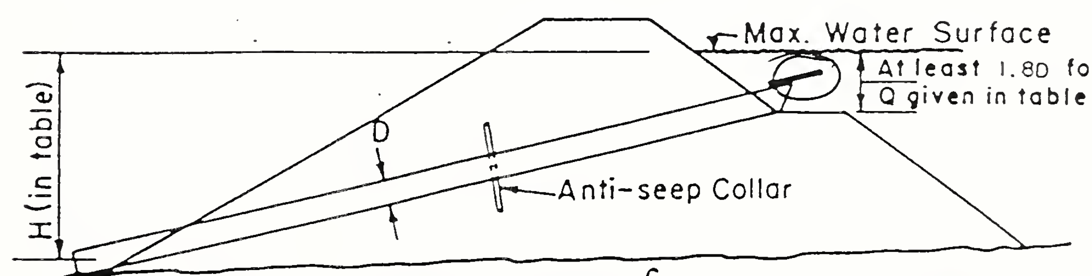


Drop spillways

Establish permanent control elevations (perm. grade control)
Water goes through free fall
Limited to 3 m drop



Corrugated metal pipe drop inlet spillway



CROSS SECTION OF DAM ON ℄ OF PIPE SPILLWAY

Chutes & Flumes

Chutes

Control of heads up to 6 m
Use less concrete than drop spillway
Hazard of undermining by rodents & seepage
Capable of higher capacity, therefore, good in locations where upstream storage (ponding) is not viable

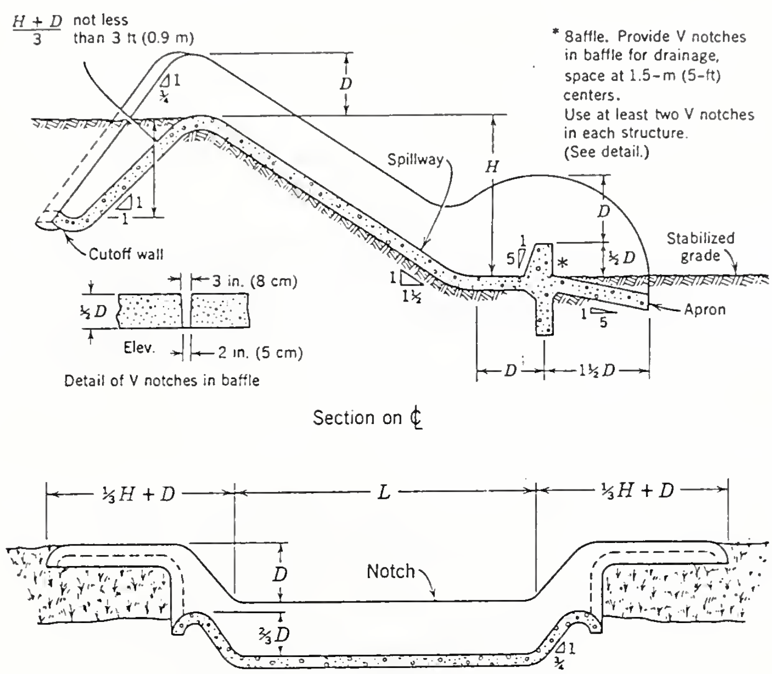


Fig. 9.12 A formless flume. (Based on design by Wooley et al., 1941.)

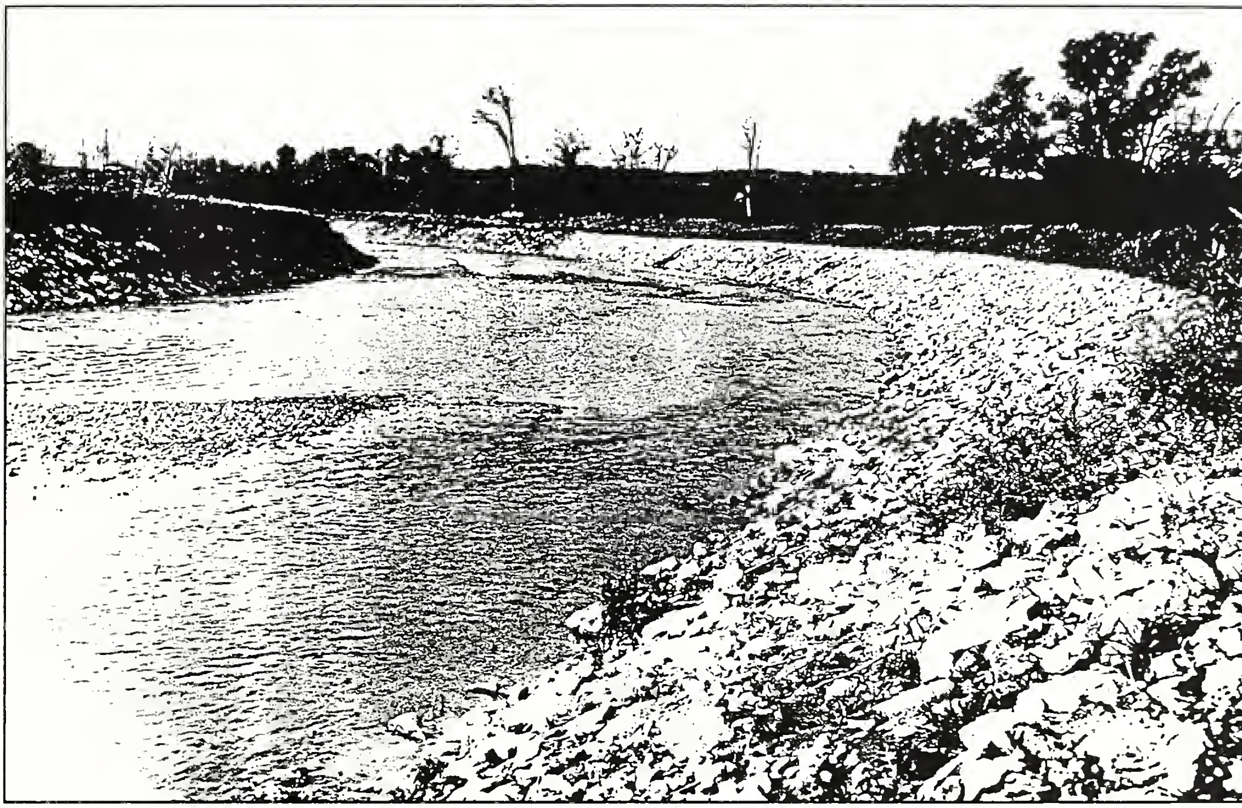
Flumes

Use for steep spots in channel
Capacity is controled by inlet section (Fig. 9.12 b)
Cheap
Limit of 2 m fall
L < 7 m
Subject to freeze and rodent damage

Erosion and Stream Protection Products/Procedures

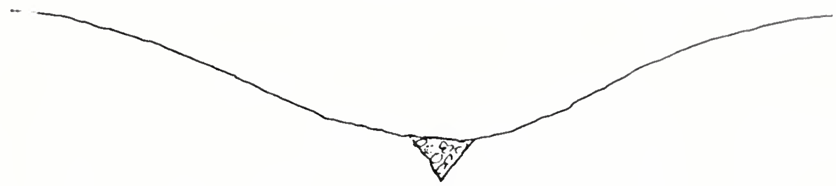
Stone

Rip-Rap - classic stream and bank form of shore protection. Usually stable when properly installed. Increases stream velocity over natural stream bank growth. May shift erosion site to unprotected bank.

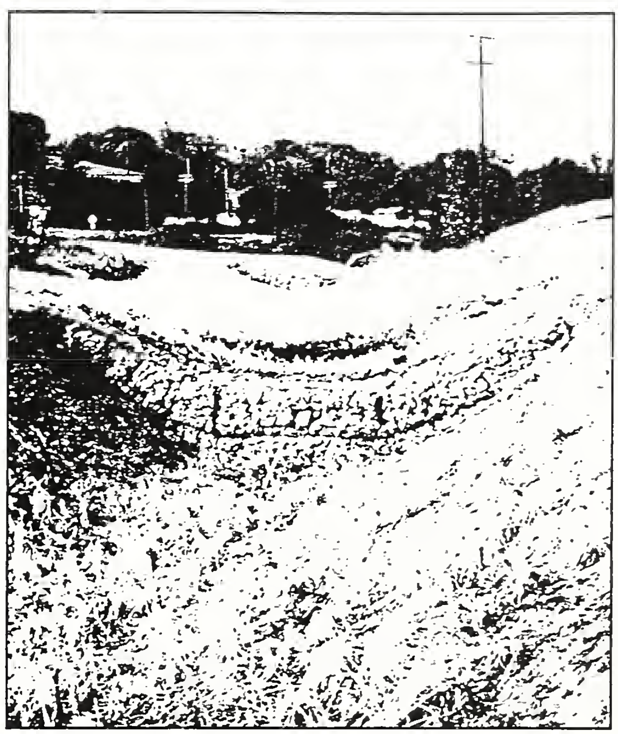


Gabions - webbing or netting made of corrosion resistant chain link fence and filled with stone. Used for both stream bank protection and structures, such as retaining walls. Some impacts are similar to rip-rap. An advantage over concrete is that the resulting structure drains well.

Wet-area Rock Channel - a "V" ditch filled with rock conveys low flows while preventing the larger channel bottom from becoming eroded. Used with grassed waterways where springs and seeps are common.



Rock Check Dams - "U" shaped stone dams positioned perpendicular to flow in channels to slow flow and to maintain slope (prevent it from getting steeper). Also used at the entrance to detention basins to spread flow and cause siltation farther up in the basin.



Netting/mesh/mats

Netting is usually a temporary measure to keep some mulch material (typically straw) in place on a slope while seed germinates and established. Often not bio-degradable. Therefore, must eventually be removed.

Channel mats or erosion mat - porous matting that is thick (1/2 inch) compared to netting and stapled in place to pass water while allowing the seed beneath the mat to germinate and establish. Available in both bio-degradable and non-degradable types.

Hydro-mulch

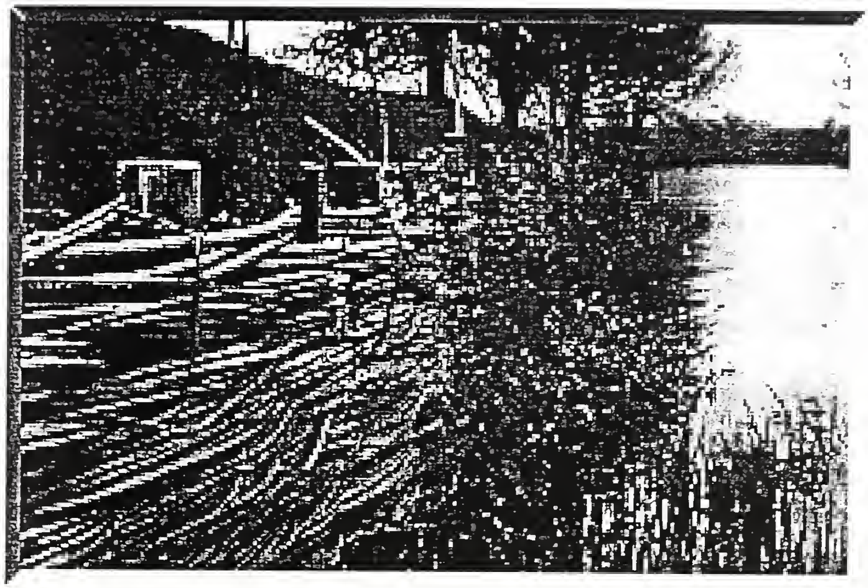
Hydro-mulch is a mixture of seed, possibly fertilizer, and a binder. The mixture is in liquid form and sprayed on slopes. Green coloring is often added. The binder/mulch hardens somewhat and resists erosion while the seed within the mulch germinates and establishes. Usually bio-degradable.

Plantings

Willows - Nowadays willows are increasingly used to control erosion along river banks. Due to the lack of scientifically established design rules the layout of soil bioengineering constructions mainly derives from experience.

Live willow stakes - for shoreline sites with low velocities and wave heights. These stakes may be used to anchor surface erosion control materials, and to repair small earth slips and slumps that are largely surficial erosion. Cuttings are usually 0.5 to 1.5 inches in diameter and 2-3 feet long, taken from vigorous, undamaged, disease and insect free stock, and either be native or adapted to the planting site. Stakes are installed 2-3 feet apart using triangular spacing with 2 to 4 stakes per square yard.

Hurdles are manufactured in both live willow or dead willow withies. Provides instant protection to river side and lake edges allowing re-establishment of vegetation. Hurdles can be planted through either in-situ or pre-planted if required. Live willow can be woven on site to suit any size or shape of application, especially for river banks where long term protection is required with a natural willow embankment.



Shore plantings include dune establishment on the ocean and SAV plantings under water. Shore plantings provide a plant mass that will reduce water energy and both survive and thrive. Typically, plantings are native species, though numerous varieties of sufficiently hardy willow are used.

Combinations

Rock rip-rap is used in combination with shore plantings to dissipate energy while the plantings establish and mature.

Willow stakes are used in rip-rap.

TABLE 1

CAUSES OF EROSION

Type of Erosion	Causes
Toe erosion and upper bank failure	Removal of unconsolidated or noncohesive lower materials, especially along outside bends. Widespread toe erosion may be associated with bed lowering.
General bed degradation (Bed scour over extended reaches)	Changes in stream gradient due to factors such as lowering of stream base level due to lake or tailwater fluctuations, stream channelization, or stream relocation. Increased stream discharge due to flow diversion or watershed changes such as urbanization.
Headcutting	In streams undergoing bed degradation, headcuts often develop at locations where more resistant materials outcrop in the stream channel. Headcuts may develop at a stream mouth when base level is lowered suddenly due to dredging, erosion or draining of a lake.
Middle and upper general bank scour	Increased discharge resulting from watershed changes; increased flow velocities caused by reduction in channel roughness or increases gradients; removal or loss of bank vegetation.
Local streambank scour	Scour of local lenses or deposits of unconsolidated material; erosion by secondary currents caused by flow obstructions and channel irregularities; loss of bank vegetation.
Local bed scour	Local bed scour may be caused by channel constrictions, flow obstructions such as debris dams or flow deflectors, or trapping of sediment in reservoirs or sediment traps. Some scour generally occurs below culverts.
Piping	Piping develops when fines are removed by water flowing laterally under the surface. Extensive pipe development requires 1) rapid infiltration, 2) steep hydraulic gradients, and 3) zones of concentrated flow. Piping may occur in stratified soils where vertical movement is restricted by sudden reduction in hydraulic conductivity between strata or where poorly compacted soil around buried pipes provides conduits for water movement.
Overbank runoff	Failure to provide adequate means of directing concentrated flows from overbank areas into the channel.

TABLE 2

APPROPRIATE PROTECTION MEASURES
(some of which are relative to the USDA/SCS workshop)

Erosion Process	Streambank Protection Ranked by Environmental Benefits
Headcutting and general bed degradation	Erosion must be halted by installing grade control, runoff detention and/or by armoring bed.
Toe erosion and upper bank failure	1. Live cribwall 2. Brushmattress 3. Rock toe with vegetation 4. Conventional riprap
Local bank scour	1. Branchpacking 2. Live cribwall 3. Live fascine 4. Joint planting 5. Tree revetment 6. Conventional vegetation 7. Conventional riprap
Local bed scour	1. Eliminate problem and armor scour hole
General scour of middle and upper bank	1. Brushmattress 2. Live fascine 3. Live staking 4. Joint planting 5. Tree revetment 6. Conventional vegetation 7. Conventional riprap

TABLE 2, Continued

APPROPRIATE PROTECTION MEASURES
(some of which are relative to the USDA.SCS workshop)

Erosion Process	Streambank Protection Ranked by Environmental Benefits
Overbank runoff	Intercept and divert runoff and repair damage with 1. Branchpacking 2. Live fascine 3. Live staking
Piping	Intercept and divert runoff Fill existing pipes and repair damage with 1. Branchpacking 2. Live staking

Types of streambank protection measures

Streambank protection measures work either by reducing the force of flowing water that attacks the bank, by increasing the resistance of the bank to erosion, or by some combination of the two processes. Stormwater reduction or retention methods, grade reduction structures, and structural designs that create turbulence and reduce flow velocity fall into the first category. Live booms and dead tree or brush retards are examples. Channels lined with grass or stone and streambanks protected by riprap, cellular concrete, or other revetment designs are of the second type. Most designs that employ brushy vegetation, either alone or in combination with structures, protect from erosion in both ways. Revetment designs do not reduce the energy of the flow significantly, and spot protection with revetments may displace erosion problems downstream or across the stream channel. Thus, it is important to consider the stream as an entity and consider the effects that stream protection may have on other reaches, surrounding wetlands, riparian habitat, aquatic habitat, water quality, and aesthetics.

Figure 7.1 A bank stabilization project with a rock toe key.

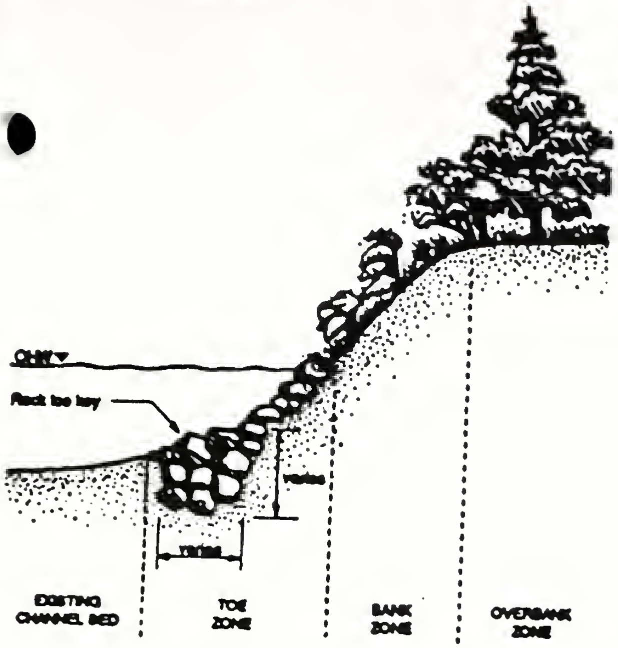
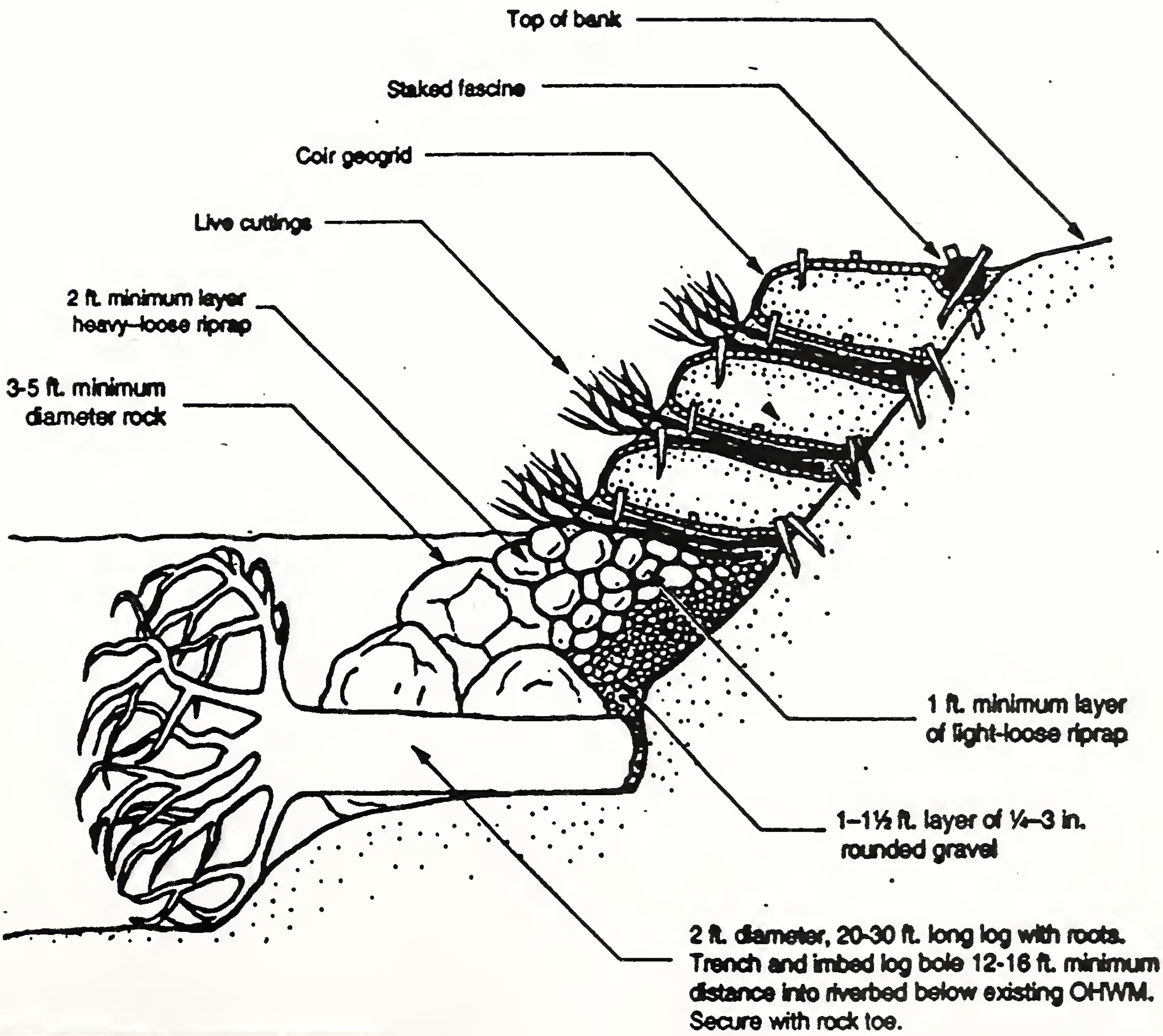


Figure 8.11 Integrated system using large woody debris.



HYDRAULIC AND SEDIMENT CHARACTERISTICS FOR ALLUVIAL STREAMS AND ASSESSMENT TOOLS

(Relations to Bioengineering Techniques)

WHAT TO ASSESS

A) CHANNEL HYDROLOGY

- river water levels and timing
- ground water levels

B) RIVER CURRENTS

- directions
- strengths
- degree of turbulence and eddying agitation
- resulting shear stress on boundaries

C) BOUNDARY CONFIGURATION

- degree of meandering
- bars and bedforms
- widths
- curvatures relative to flow
- rates of change of shape
- bank slopes
- bank toes

D) BOUNDARY MATERIALS

- bank materials
- bed materials
- looseness versus tightness/cohesiveness
- vertical changes in kinds of materials

E) EROSION AND DEPOSITION

- rates
- locations and critical points
- material sizes and types

KINDS OF ASSESSMENTS

A) HYDROLOGIC -- influences/effects on banks

- frequency of risk
- magnitude of risk
- project work "window"
- growing season vis-a-vis work period and risk

B) HYDRAULIC -- influences/effects on banks

- velocities
- velocity patterns
- energy gradients
- shear stresses
- bed/bank agitation by flow

C) CHANNEL BOUNDARIES

- banks
  - soils/alluvium
  - vegetation
  - layering
  - variability
- bed
  - alluvial materials
  - form and structure
  - variability

D) CHANNEL MORPHOLOGY

- planforms
- bedforms
- bars
- influences/effects on banks

E) SEDIMENT TRANSPORT

- suspended load characteristics
- bed load characteristics
- scour and deposition
- profile degradation or aggradation

F) WATERSHED INFLUENCES

HYDROLOGIC ASSESSMENTS

-- influences/effects on banks

WHAT TO ASSESS

- river water levels and timing
- ground water levels

KINDS OF ASSESSMENTS

- frequency of risk
- magnitude of risk
- project work "window"
- growing season vis-a-vis work period and risk

HYDROLOGIC CONDITIONS TO BE EXPECTED

- snowmelt-runoff regimes
- rainfall runoff regimes
- mixed rainfall and snowmelt-runoff regimes
- differences between tributaries and main-trunk rivers

HYDRAULIC ASSESSMENTS

-- influence/effects on banks

WHAT TO ASSESS

- river currents (velocities / depths / patterns)
  - directions
  - strengths
  - degree of turbulence and eddying agitation
- river and energy gradients
  - for reach
  - local variations
- resulting shear stress on boundaries

KINDS OF ASSESSMENTS

- velocities
- velocity patterns
- water slopes and energy gradients
- eddies, flow separation, and wakes
- shear stresses
- bed/bank agitation by flow

HYDRAULIC CONDITIONS TO BE EXPECTED

vertical, lateral and longitudinal variations
in all conditions

straight channels
bends
irregular channels
varying velocities and depths
varying water slopes and energy gradients
local eddies, flow separation and wakes

CHANNEL BOUNDARIES

AND

CHANNEL MORPHOLOGY

WHAT TO ASSESS

Boundary Configuration

- degree of meandering
- bars and bedforms
- widths
- curvatures relative to flow
- rates of change of shape
- bank slopes
- bank toes

Boundary Materials

- bank materials
- bed materials
- looseness versus tightness/cohesiveness
- vertical changes in kinds of materials

KINDS OF ASSESSMENTS

Channel Boundaries

- banks
  - soils/alluvium
  - vegetation
  - layering
  - variability
- bed
  - alluvial materials
  - form and structure
  - variability

Channel Morphology

- planforms
- bedforms
- bars
- influences/effects on banks

BOUNDARY AND MORPHOLOGICAL CONDITIONS TO BE EXPECTED

SEDIMENT TRANSPORT ASSESSMENTS

WHAT TO ASSESS

- erosion and deposition rates
- erosion/deposition locations and critical points
- material sizes and types

KINDS OF ASSESSMENTS

- transport modes
- suspended load characteristics
- bed load characteristics
- effects of channel boundaries
  - local effects
  - large-scale effects
- scour and deposition
- profile degradation or aggradation

SEDIMENT TRANSPORT CONDITIONS TO BE EXPECTED

double-condition applies
- flow capability to transport sediment
- sediment availability for transport

frequent transport of suspended matter
infrequent transport of bed material

source-transport-storage-sink relations

SUMMARY OF CONCLUSIONS

1. BIOENGINEERING TECHNIQUES CAN PROTECT STREAMBANKS

- IN SEVERAL WAYS;
- IN SOME SITUATIONS.

A) THEY CAN HELP

- increase bank resistance
- deflect flow away from bank
- reduce flow velocity below erosive strength
- dissipate flow energy
- delay erosion (if only partly effective)

B) THEY ARE USEFUL

- when currents are small/moderate
- where banks are not too steep
- where banks are not being undercut

C) They can be used

- alone in some situations
- in combination with structural protection

2. WHAT TO ASSESS

A) CHANNEL HYDROLOGY
B) RIVER CURRENTS
C) BOUNDARY CONFIGURATION
D) BOUNDARY MATERIALS
E) EROSION AND DEPOSITION

3. KINDS OF ASSESSMENTS

A) HYDROLOGIC -- influences/effects on banks
B) HYDRAULIC -- influences/effects on banks
C) CHANNEL BOUNDARIES
D) CHANNEL MORPHOLOGY
E) SEDIMENT TRANSPORT
F) WATERSHED INFLUENCES

Table 1. Hierarchy of river inventories.

Level of Detail	Inventory Description	Information Required	Objectives
I	Broad morphological characterization	Landform, lithology, soils, climate, depositional history, basin relief, valley morphology, river profile morphology, general river pattern	To describe generalized fluvial features using remote sensing and existing inventories of geology, landform evolution, valley morphology, depositional history and associated river slopes, relief and patterns utilized for generalized categories of major stream types and associated interpretations.
II	Morphological description (stream types)	Channel patterns, entrenchment ratio, width/depth ratio, sinuosity, channel material, slope	This level delineates homogeneous stream types that describe specific slopes, channel materials, dimensions and patterns from "reference reach" measurements. Provides a more detailed level of interpretation and extrapolation than Level I.
III	Stream "state" or condition	Riparian vegetation, depositional patterns, meander patterns, confinement features, fish habitat indices, flow regime, river size category, debris occurrence, channel stability index, bank erodibility	The "state" of streams further describes existing conditions that influence the response of channels to imposed change and provide specific information for prediction methodologies (such as stream bank erosion calculations, etc.). Provides for very detailed descriptions and associated prediction/interpretation.
IV	Monitoring	Involves direct measurements/observations of sediment transport, bank erosion rates, aggradation/degradation processes, hydraulic geometry, biological data such as fish biomass, aquatic insects, riparian vegetation evaluations, etc.	Provides reach-specific information on channel processes. Used to evaluate prediction methodologies; to provide sediment, hydraulic and biological information related to specific stream types; and to evaluate effectiveness of mitigation and impact assessments for activities by stream type.

Table 2. Summary of delineative criteria for broad-level classification.

Stream Type	General Description	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Landform/Soils/Features
Aa+	Very steep, deeply entrenched ,debris transport streams.	<1.4	<12	1.0 to 1.1	>.10	Very high relief. Erosional, bedrock or depositional features; debris flow potential. Deeply entrenched streams. Vertical steps with/deep scour pools; waterfalls.
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder dominated channel.	<1.4	<12	1.0 to 1.2	.04 to .10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step-pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4 to 2.2	>12	>1.2	.02 to .039	Moderate relief, colluvial deposition and/or residual soils. Moderate entrenchment and W/D ratio. Narrow, gently sloping valleys. Rapids predominate w/occasional pools.
C	Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad,well defined floodplains	>2.2	>12	>1.4	<.02	Broad valleys w/terraces, in association with floodplains, alluvial soils. Slightly entrenched with well-defined meandering channel. Riffle-pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	>40	n/a	<.04	Broad valleys with alluvial and colluvial fans. Glacial debris and depositional features. Active lateral adjustment, w/abundance of sediment supply.
DA	Anastomosing (multiple channels) narrow and deep with expansive well vegetated floodplain and associated wetlands. Very gentle relief with highly variable sinuosities. stable streambanks.	>4.0	<40	variable	<.005	Broad, low-gradient valleys with fine alluvium and/or lacustrine soils. Anastomosed (multiple channel) geologic control creating fine deposition w/well-vegetated bars that are laterally stable with broad wetland floodplains.
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<.02	Broad valley/meadows. Alluvial materials with floodplain. Highly sinuous with stable, well vegetated banks. Riffle-pool morphology with very low width/depth ratio.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.	<1.4	>12 (>12)	>1.4	<.02	Entrenched in highly weathered material. Gentle gradients, with a high W/D ratio. Meandering, laterally unstable with high bank-erosion rates. Riffle-pool morphology.
G	Entrenched "gulley" step/pool and low width/depth ratio on moderate gradients.	<1.4	<12	>1.2	.02 to .039	Gulley, step-pool morphology w/moderate slopes and low W/D ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials; i.e., fans or deltas. Unstable, with grade control problems and high bank erosion rates.

Table 3. Management interpretations of various stream types.

Stream Type	Sensitivity to Disturbance[1]	Recovery Potential[2]	Sediment Supply[3]	Streambank Erosion Potential	Vegetation Controlling Influence[4]
A1	very low	excellent	very low	very low	negligible
A2	very low	excellent	very low	very low	negligible
A3	very high	very poor	very high	high	negligible
A4	extreme	very poor	very high	very high	negligible
A5	extreme	very poor	very high	very high	negligible
A6	high	poor	high	high	negligible
B1	very low	excellent	very low	very low	negligible
B2	very low	excellent	very low	very low	negligible
B3	low	excellent	low	low	moderate
B4	moderate	excellent	moderate	low	moderate
B5	moderate	excellent	moderate	moderate	moderate
B6	moderate	excellent	moderate	low	moderate
C1	low	very good	very low	low	moderate
C2	low	very good	low	low	moderate
C3	moderate	good	moderate	moderate	very high
C4	very high	good	high	very high	very high
C5	very high	fair	very high	very high	very high
C6	very high	good	high	high	very high
D3	very high	poor	very high	very high	moderate
D4	very high	poor	very high	very high	moderate
D5	very high	poor	very high	very high	moderate
D6	high	poor	high	high	moderate
DA4	moderate	good	very low	low	very high
DA5	moderate	good	low	low	very high
DA6	moderate	good	very low	very low	very high
E3	high	good	low	moderate	very high
E4	very high	good	moderate	high	very high
E5	very high	good	moderate	high	very high
E6	very high	good	low	moderate	very high
F1	low	fair	low	moderate	low
F2	low	fair	moderate	moderate	low
F3	moderate	poor	very high	very high	moderate
F4	extreme	poor	very high	very high	moderate
F5	very high	poor	very high	very high	moderate
F6	very high	fair	high	very high	moderate
G1	low	good	low	low	low
G2	moderate	fair	moderate	moderate	low
G3	very high	poor	very high	very high	high
G4	extreme	very poor	very high	very high	high
G5	extreme	very poor	very high	very high	high
G6	very high	poor	high	high	high

[1] Includes increases in streamflow magnitude and timing and/or sediment increases.
[2] Assumes natural recovery once cause of instability is corrected.
[3] Includes suspended and bedload from channel derived sources and/or from stream adjacent slopes.
[4] Vegetation that influences width/depth ratio-stability.

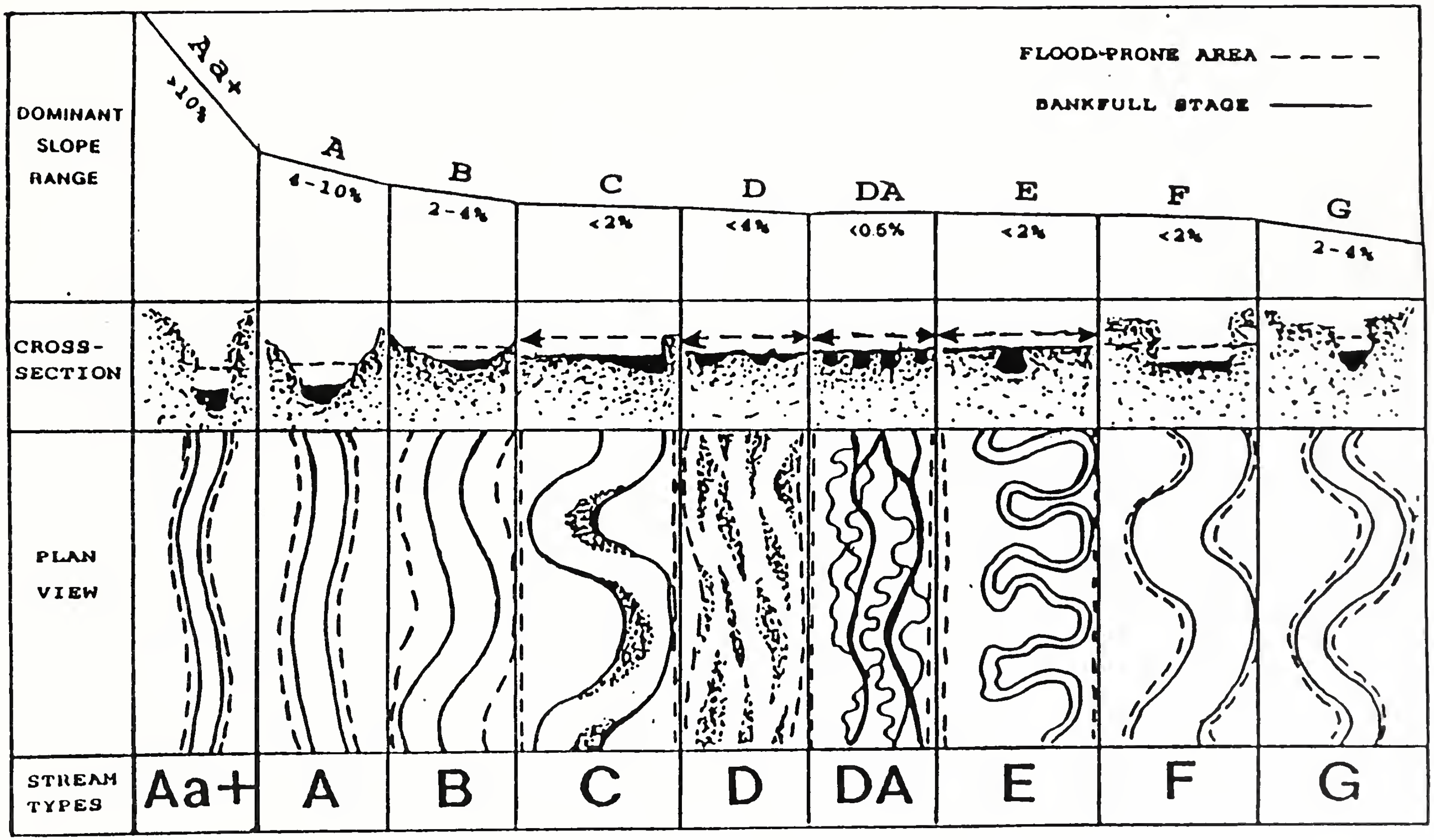


Figure 1. Longitudinal, cross-sectional and plan views of major stream types.

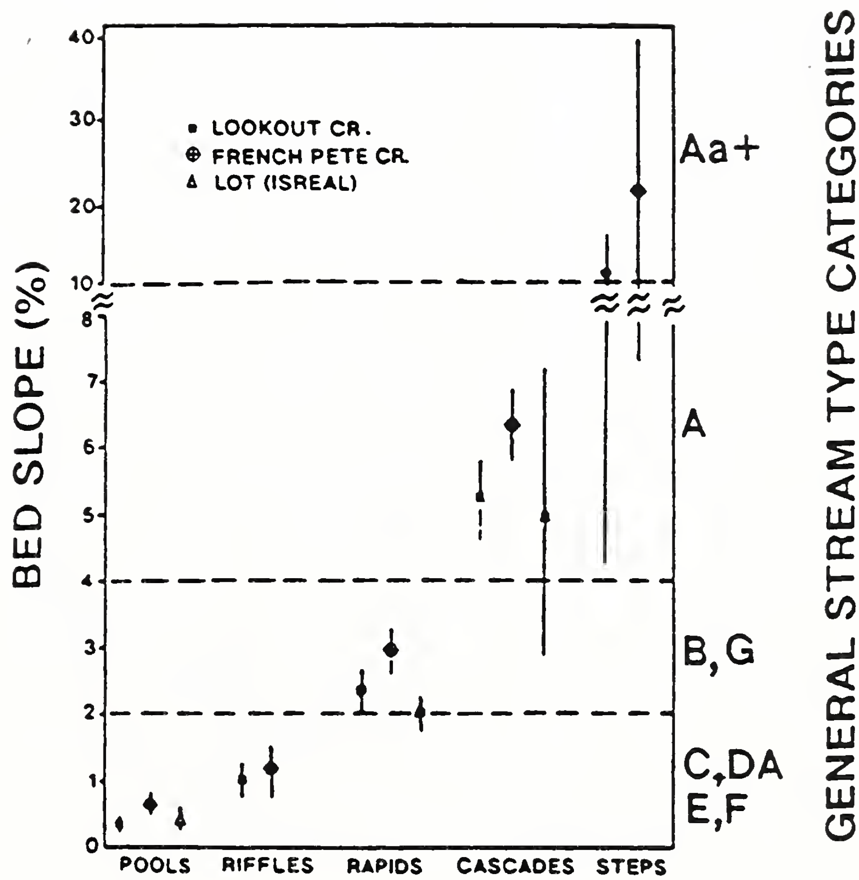


Figure 2. Relationship of bed slope to bed forms (from Grant et al., 1990) for various stream types.

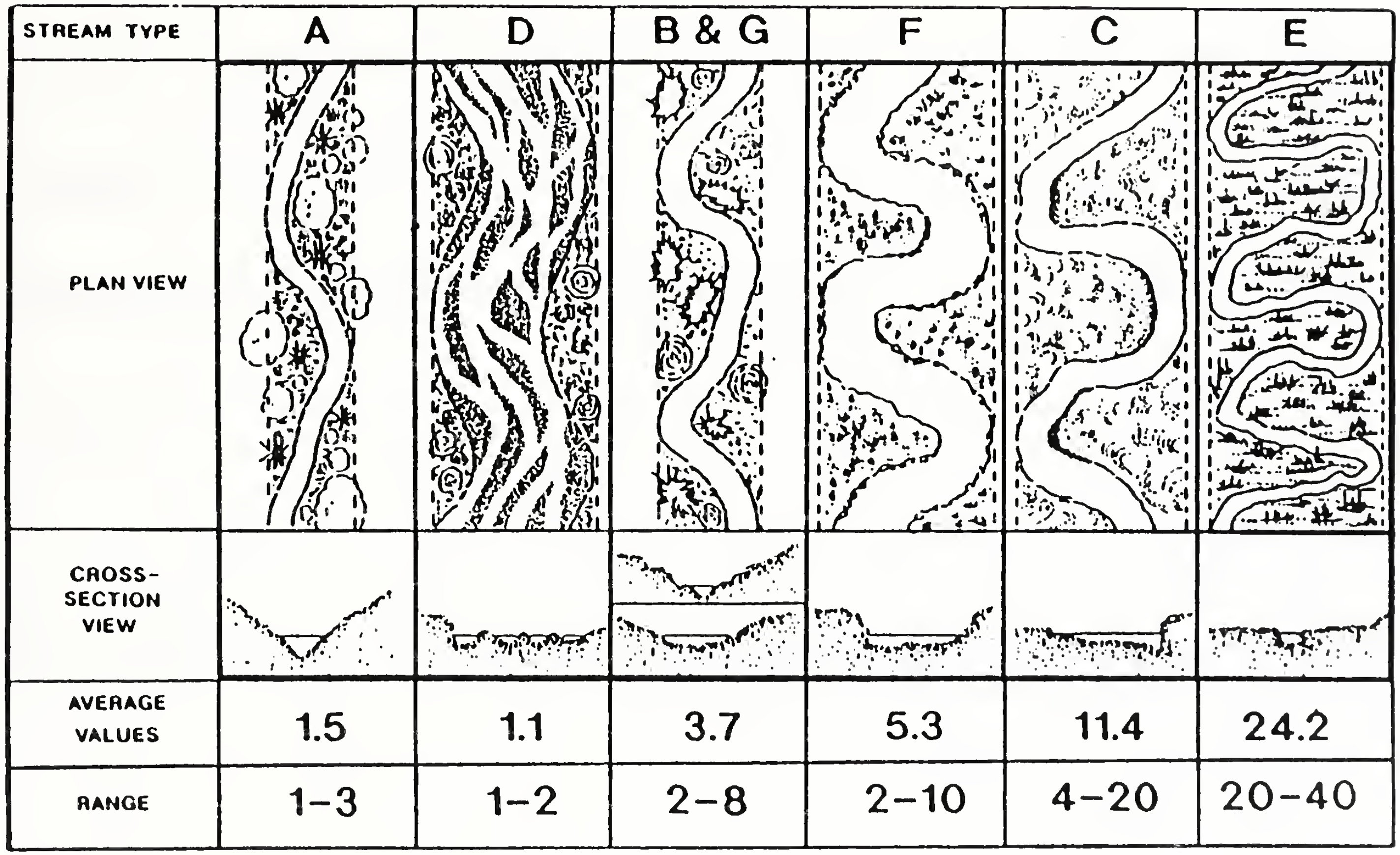
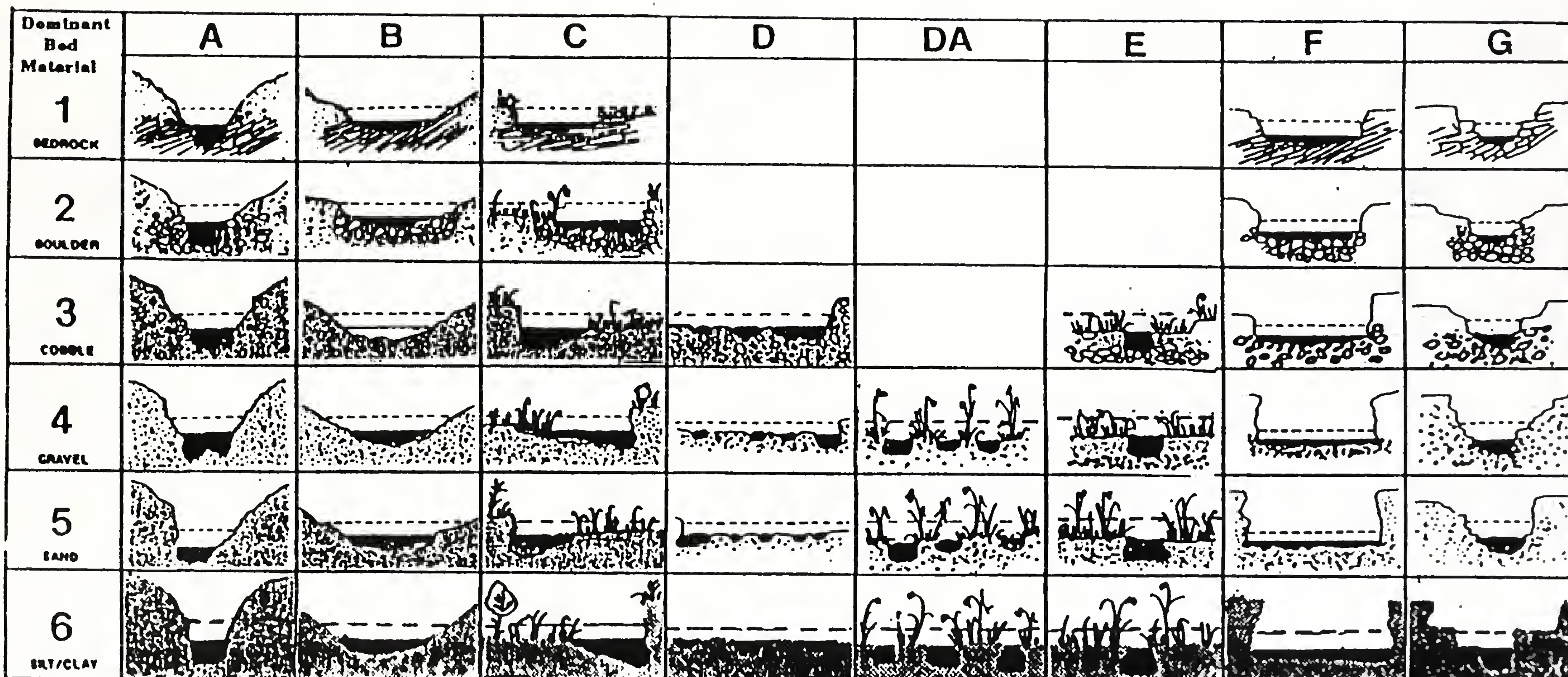
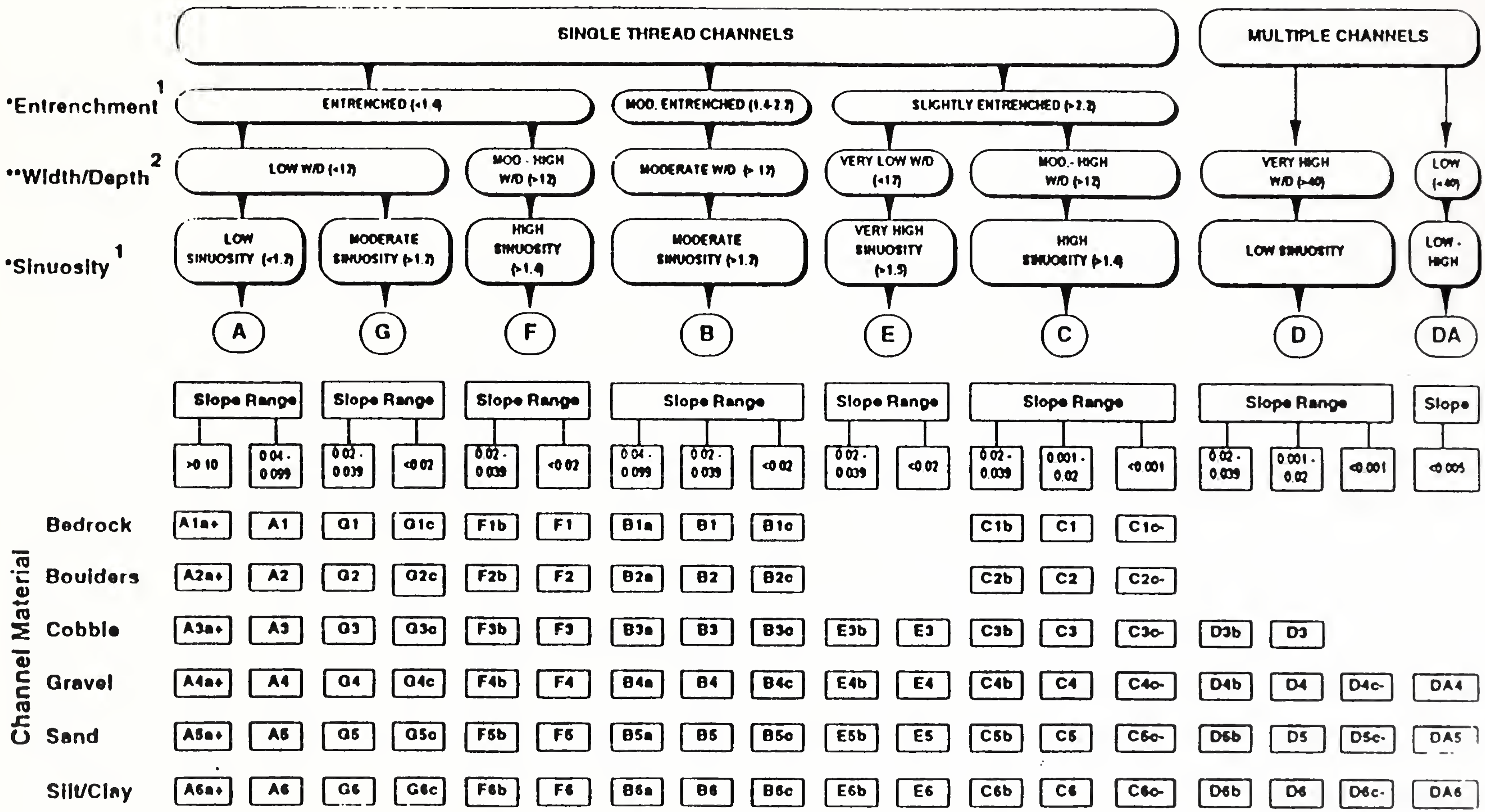


Figure 3. Meander width ratio (belt width/bankfull width) by stream type categories.



	A	B	C	D	DA	E	F	G
ENTRH.	<1.4	1.4–2.2	>2.2	N/A	>2.2	>2.2	<1.4	<1.4
SIN.	<1.2	>1.2	>1.4	<1.1	1.1-1.6	>1.5	>1.4	>1.2
W/D	<12	>12	>12	>40	<40	<12	>12	<12
SLOPE	.04–.099	.02–.039	<.02	<.02	<.005	<.02	<.02	.02–.039

Figure 4. Illustrative guide showing cross-sectional configuration, composition and delineative criteria of major stream types.



1 Values can vary by ± 0.2 units as a function of the continuum of physical variables within stream reaches.

2 Values can vary by ± 2.0 units as a function of the continuum of physical variables within stream reaches.

Figure 5. Key to classification of natural rivers.

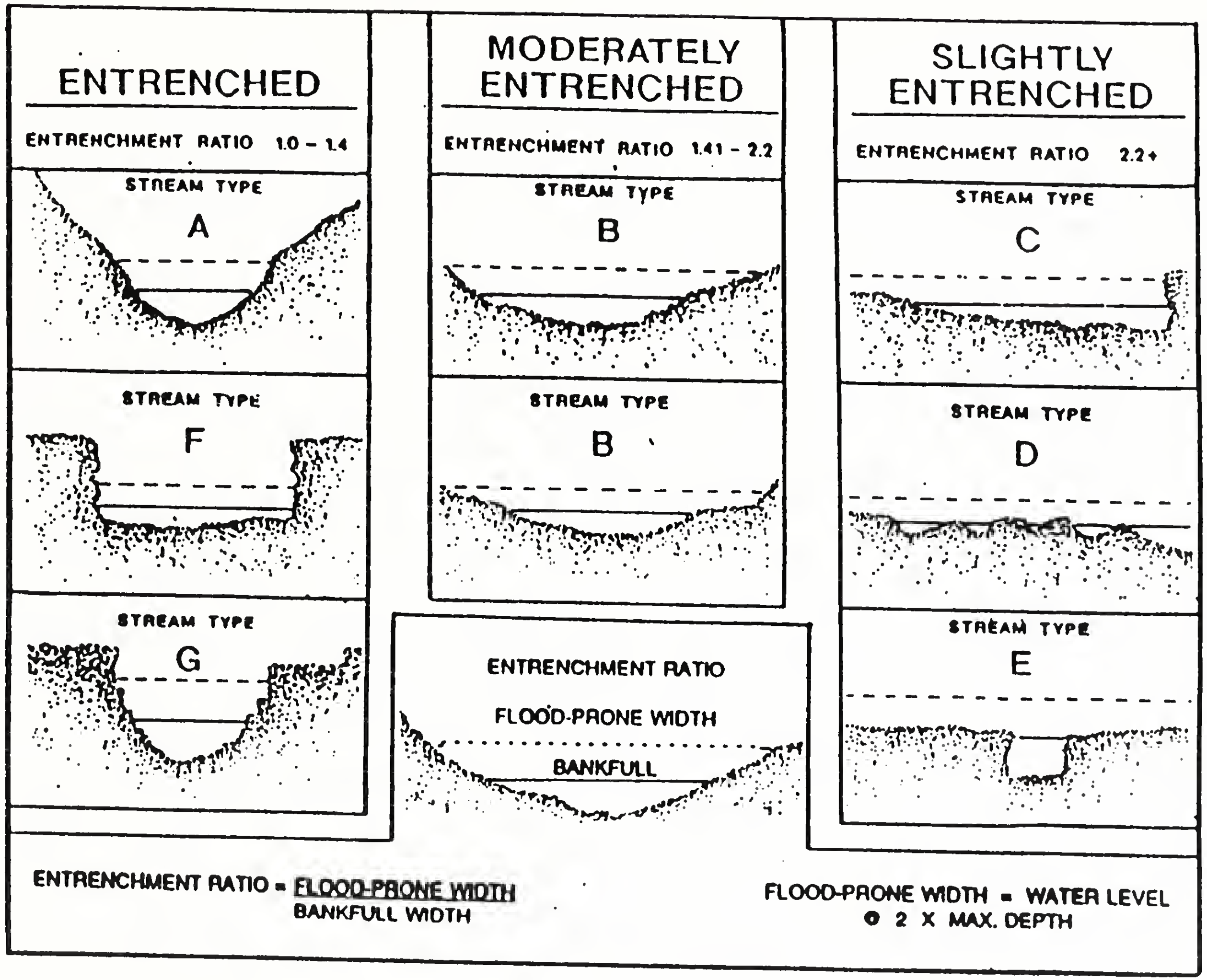


Figure 6. Examples and calculations of channel entrenchment.

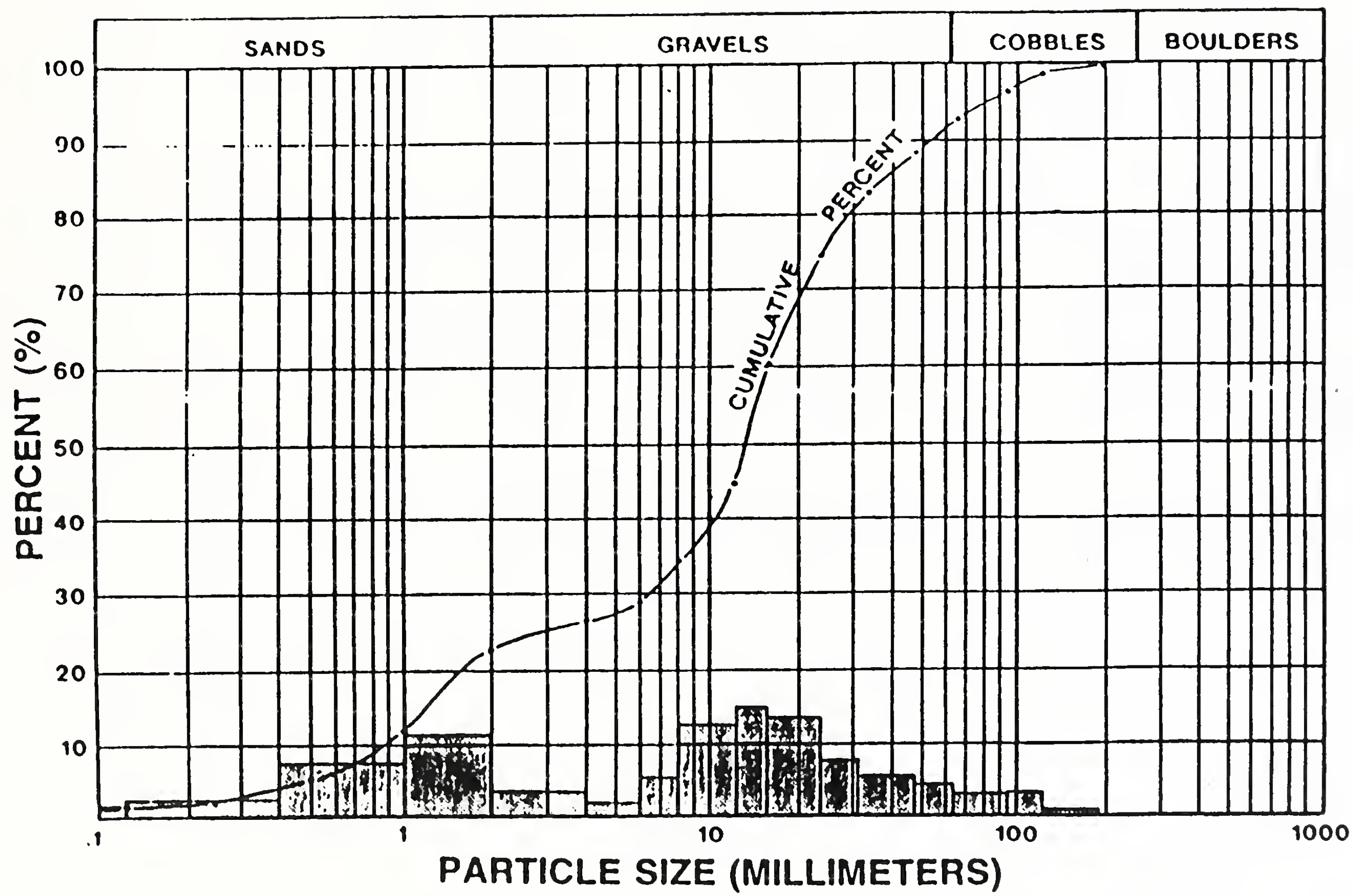


Figure 7. Channel material sizes showing cumulative and percent distributions.

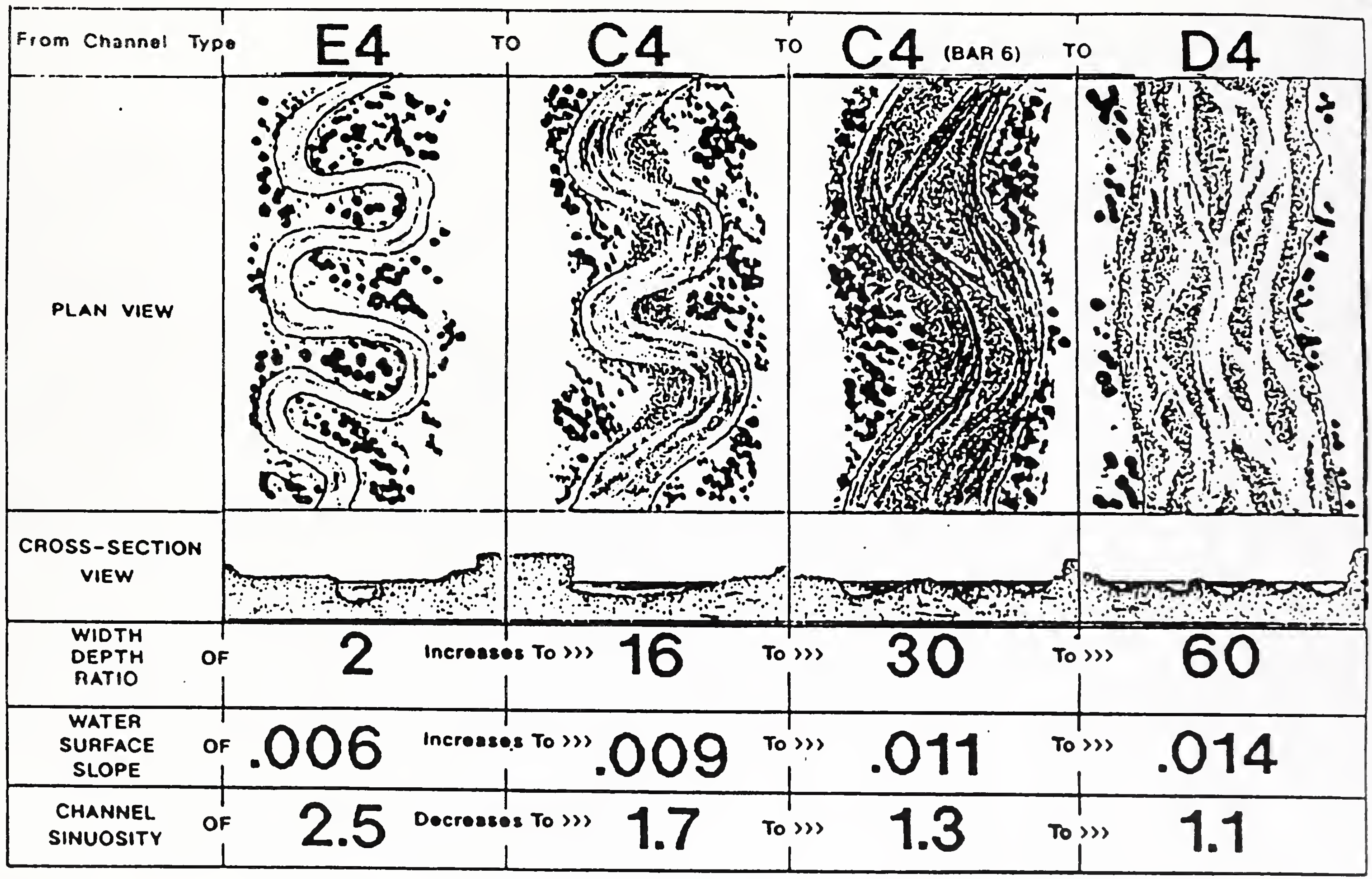


Figure 8. Progressive stages of channel adjustment due to imposed stream bank instability.

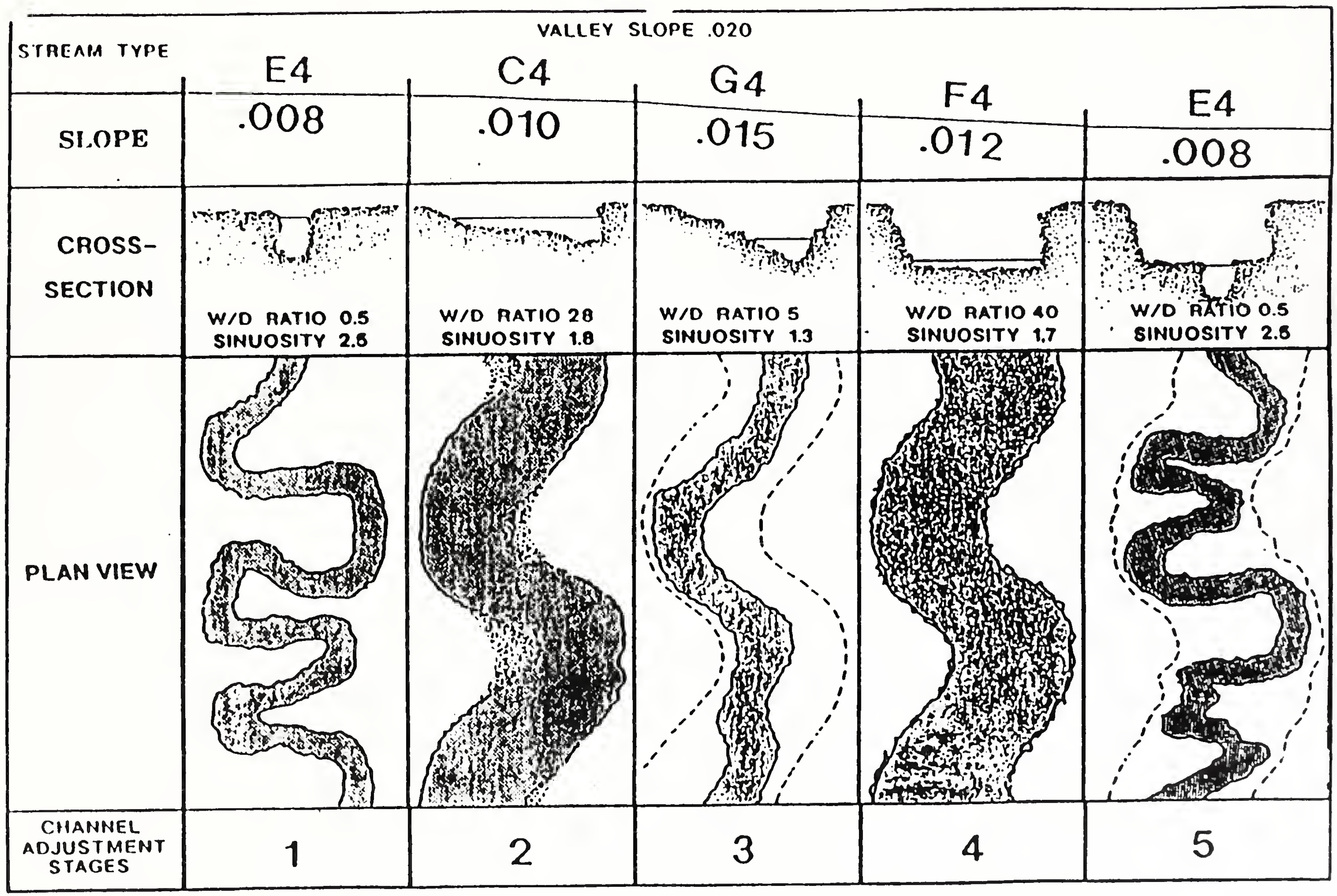


Figure 9. Evolutionary stages of channel adjustment.

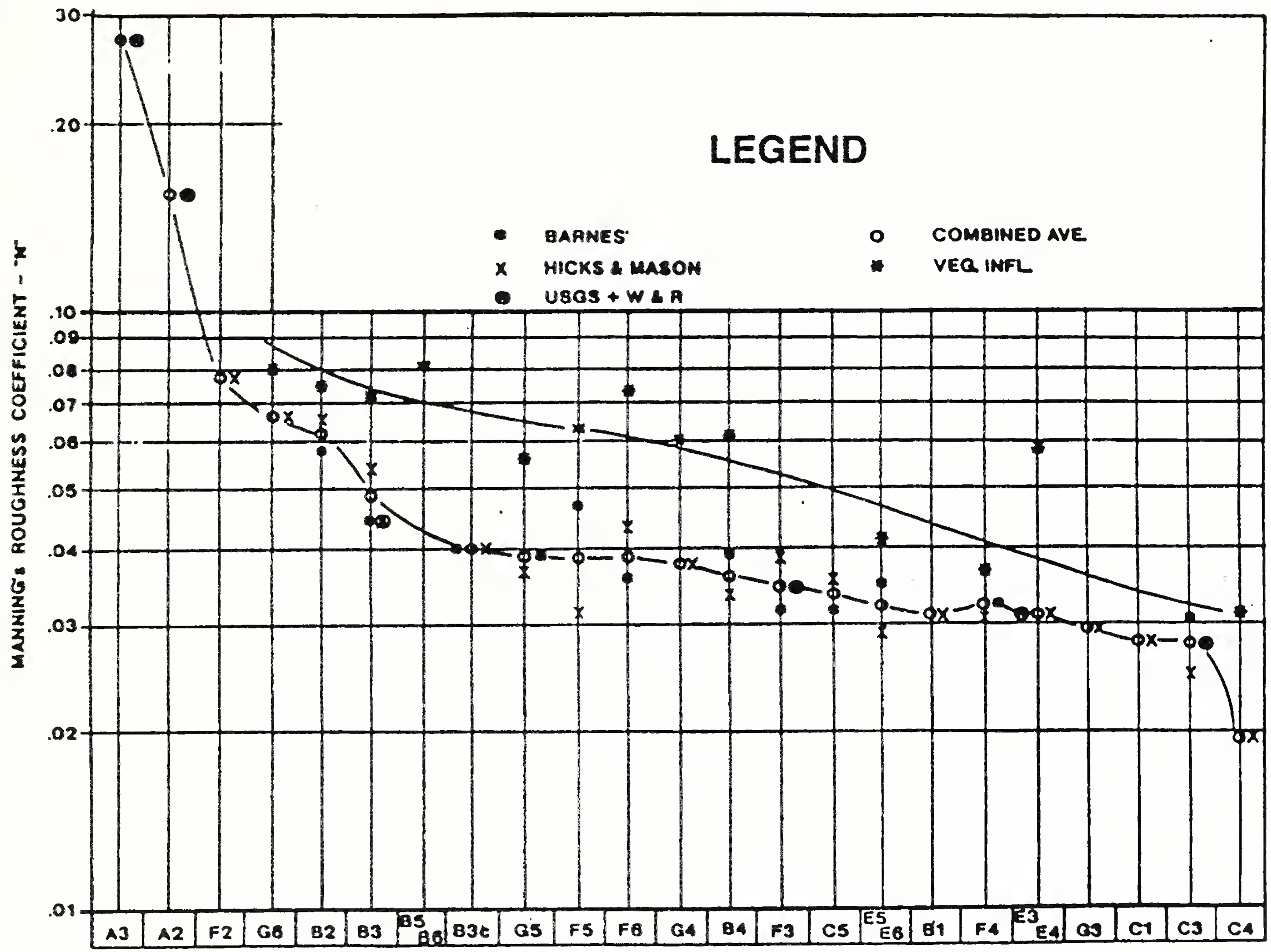


Figure 10. Bankfull stage roughness coefficients ("N" values) by stream type for 140 streams from the United States and New Zealand.

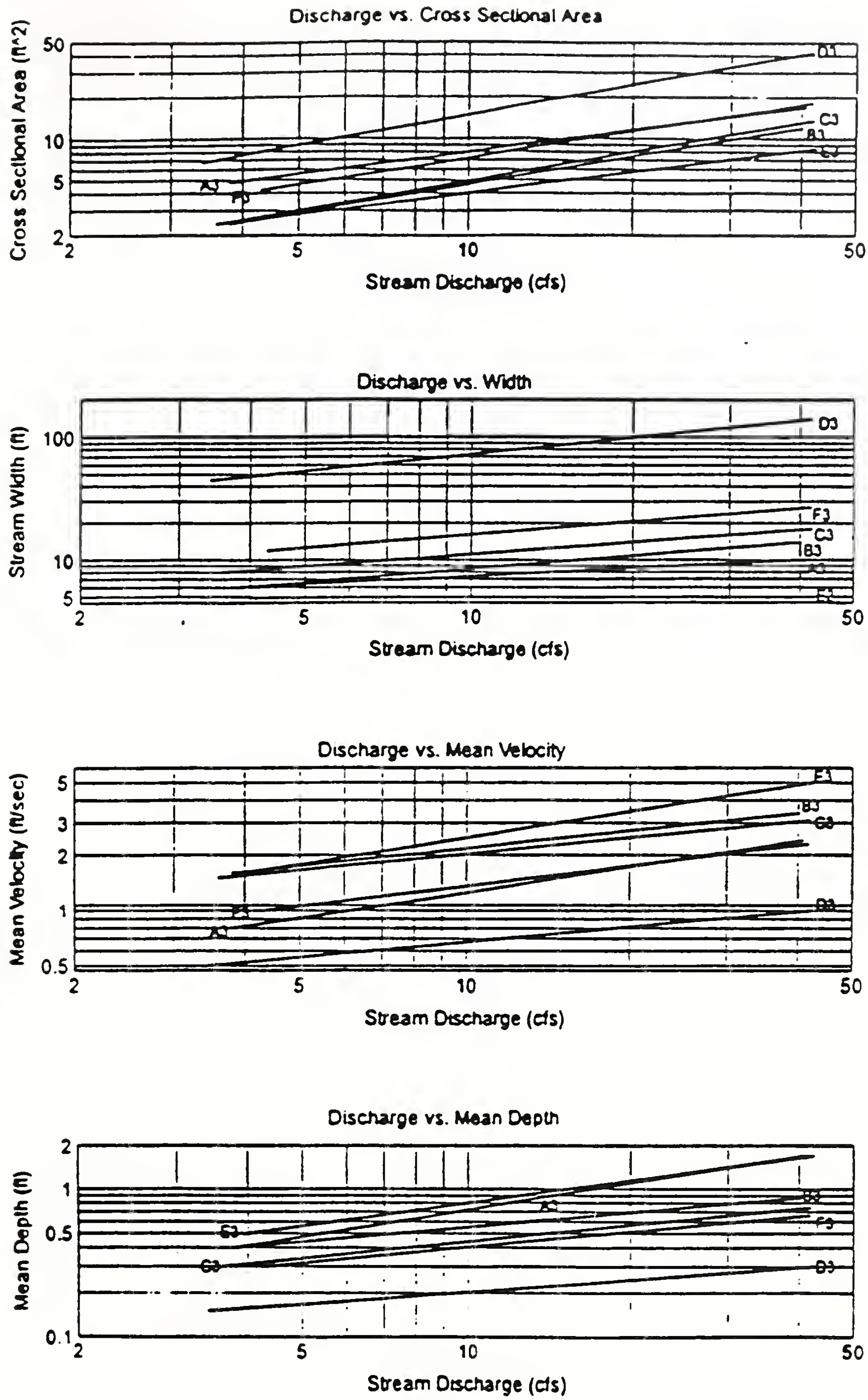


Figure 11. Hydraulic geometry relations for selected stream types of uniform size.

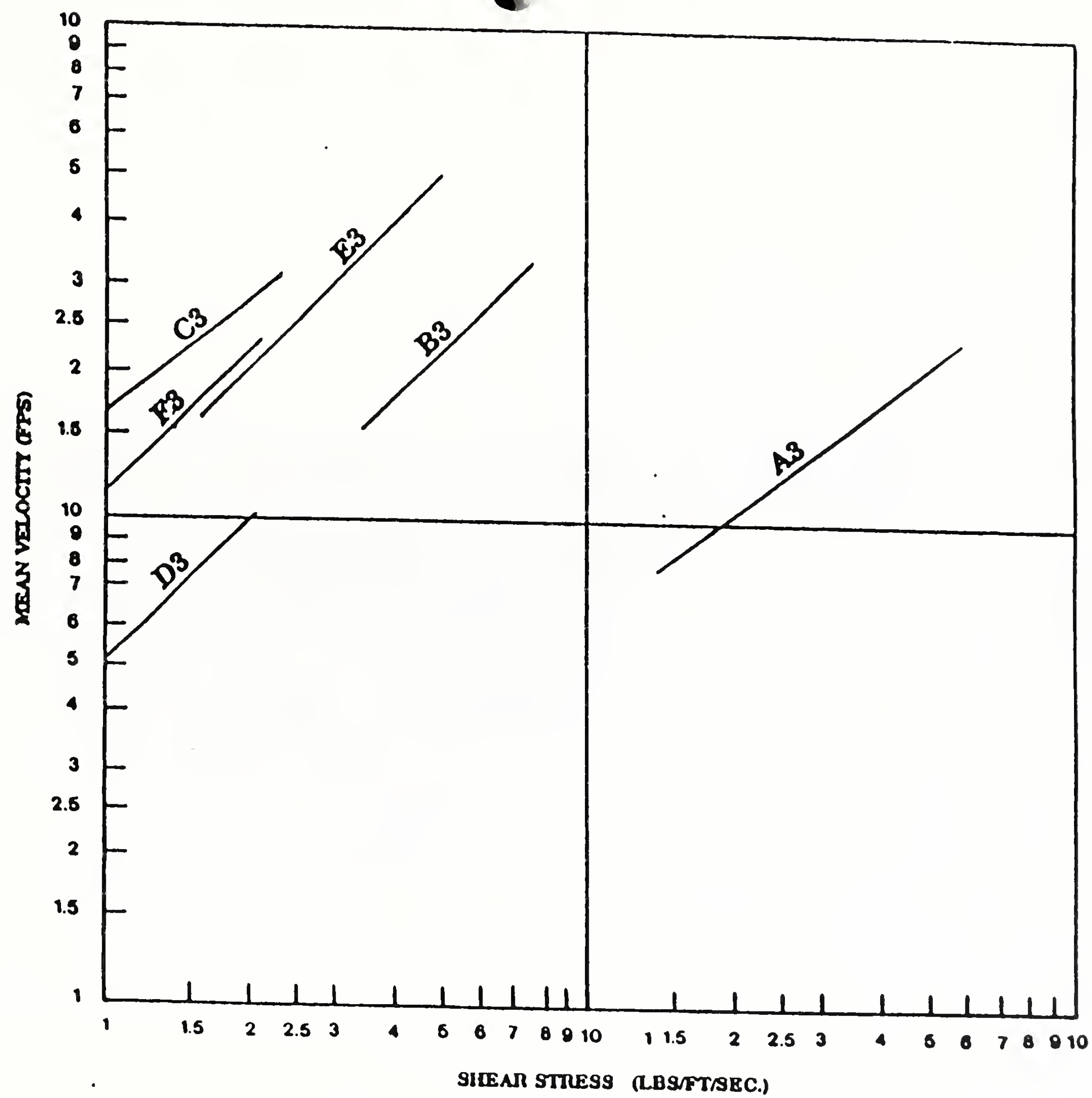


Figure 12. Relationship of mean velocity vs. shear stress for six stream types from base flow (3-4 cfs) to bankfull discharge(40-41 cfs) .

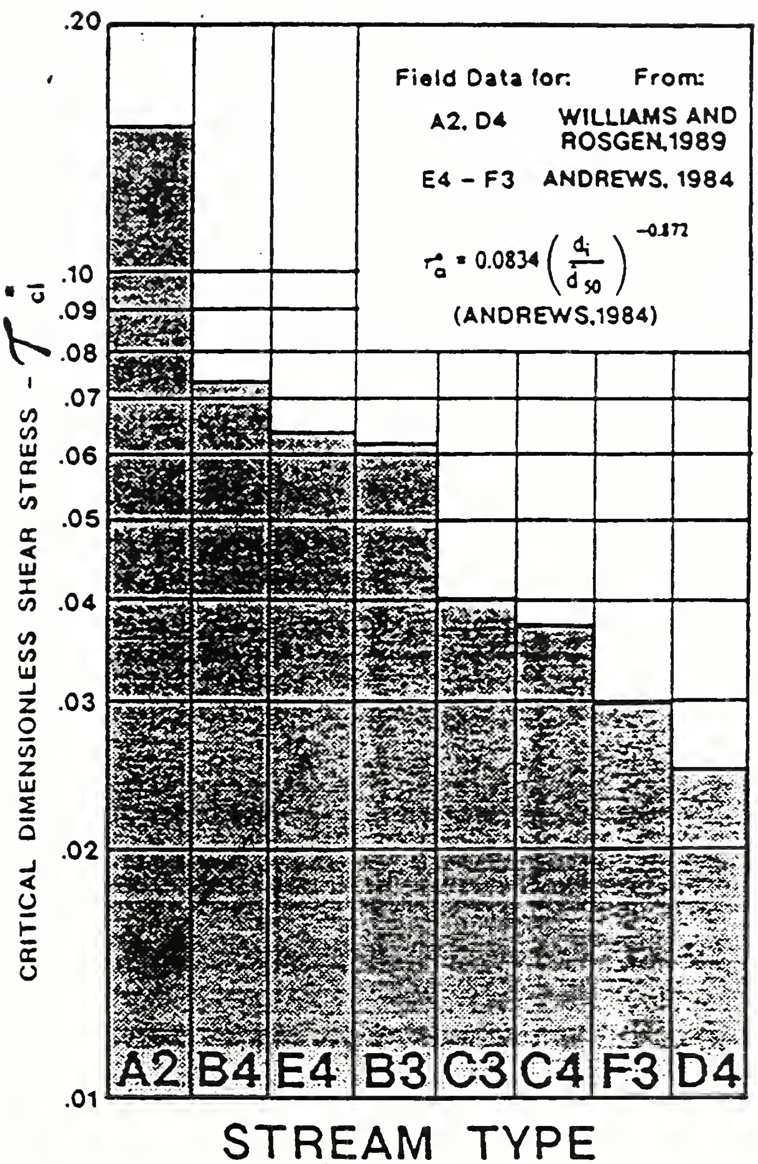


Figure 13. Relationship of field verification of critical dimensionless shear stress values for various stream types.

Table 4. Bank erodibility hazard rating guide (Rosgen, 1990).

	BANK EROSION POTENTIAL											
CRITERIA	VERY LOW		LOW		MODERATE		HIGH		VERY HIGH		EXTREME	
	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX
Bank Ht/Bkf Ht	1.0-1.1	1.0-1.9	1.11-1.19	2.0-3.9	1.2-1.5	4.0-5.9	1.6-2.1	6.0-7.9	2.1-2.8	8.0-9.0	>2.8	10
Root Depth/Bank Ht	1.0-0.9	1.0-1.9	0.89-0.50	2.0-3.9	0.49-0.30	4.0-5.9	0.29-0.15	6.0-7.9	0.14-.05	8.0-9.0	.05	10
Root Density (%)	80-100	1.0-1.9	55-79	2.0-3.9	30-54	4.0-5.9	15-29	6.0-7.9	5-14	8.0-9.0	<5	10
Bank Angle (Degrees)	0-20	1.0-1.9	21-60	2.0-3.9	61-80	4.0-5.9	81-90	6.0-7.9	90-119	8.0-9.0	120+	10
Surface Prot. (%)	80-100	1.0-1.9	55-79	2.0-3.9	30-54	4.0-5.9	15-29	6.0-7.9	10-15	8.0-9.0	<10	10
TOTALS												
		5-9.5		10-19.5		20-29.5		30-39.5		40-45		46-50
Numerical Adjustments												

BANK MATERIALS:
BEDROCK: BANK EROSION POTENTIAL ALWAYS VERY LOW
BOULDERS: BANK EROSION POTENTIAL LOW
COBBLE: DECREASE BY ONE CATEGORY UNLESS MIXTURE OF GRAVEL/SAND IS OVER 50%, THEN NO ADJUSTMENT
GRAVEL: ADJUST VALUES UP BY 5-10 POINTS DEPENDING ON COMPOSITION OF SAND
SAND: ADJUST VALUES UP BY 10 POINTS
SILT/CLAY: NO ADJUSTMENT

STRATIFICATION: 5-10 POINTS (UPWARD) DEPENDING ON POSITION OF UNSTABLE LAYERS IN RELATION TO BANKFULL STAGE

STREAM BANK ERODIBILITY FACTORS

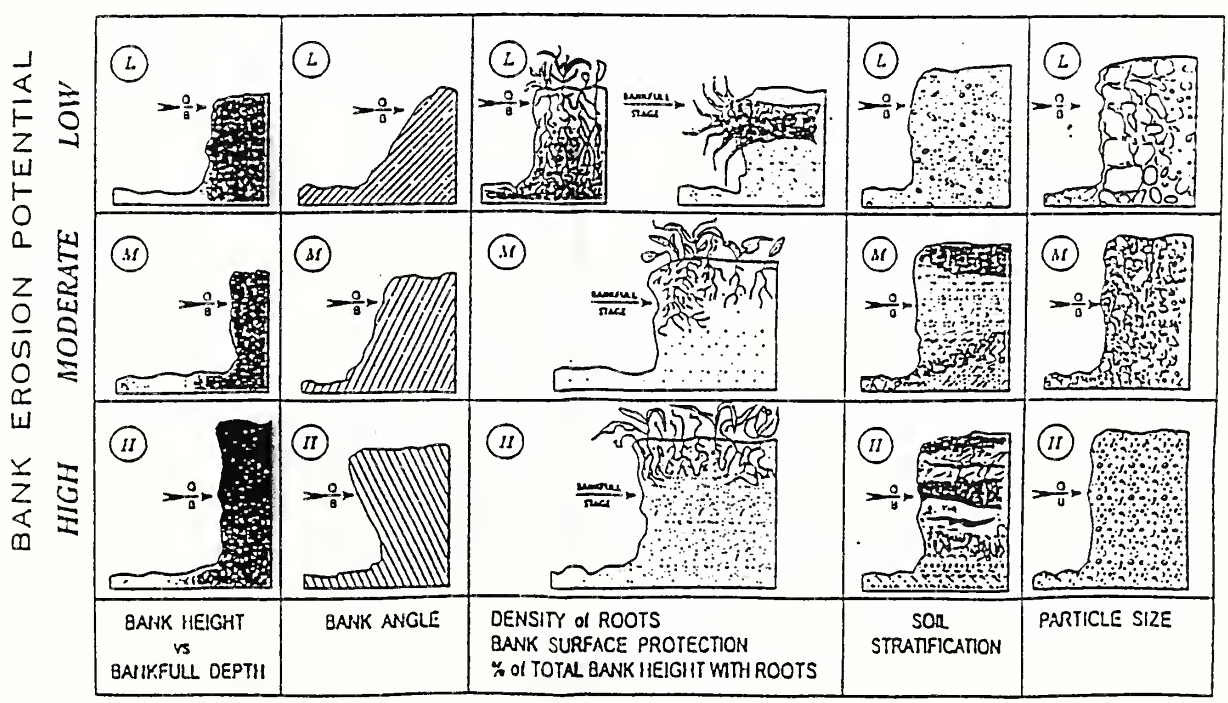


FIGURE VI-10 FLOOD PLAIN DEVELOPMENT MODEL OF JACOBSON AND COLEMAN (1986).

("Schematic representation of three-stage development of Maryland Piedmont flood plains. Pre-settlement period (PS): undisturbed stream in natural regime. Agricultural period (A): excessive upland erosion, and flood plain sedimentation. Very Recent period (VR): reduced sediment load, reworking of flood plain sediment and redeposition of coarsest sediment as new, lower flood plain level"; quoted from Jacobson and Coleman, 1986).

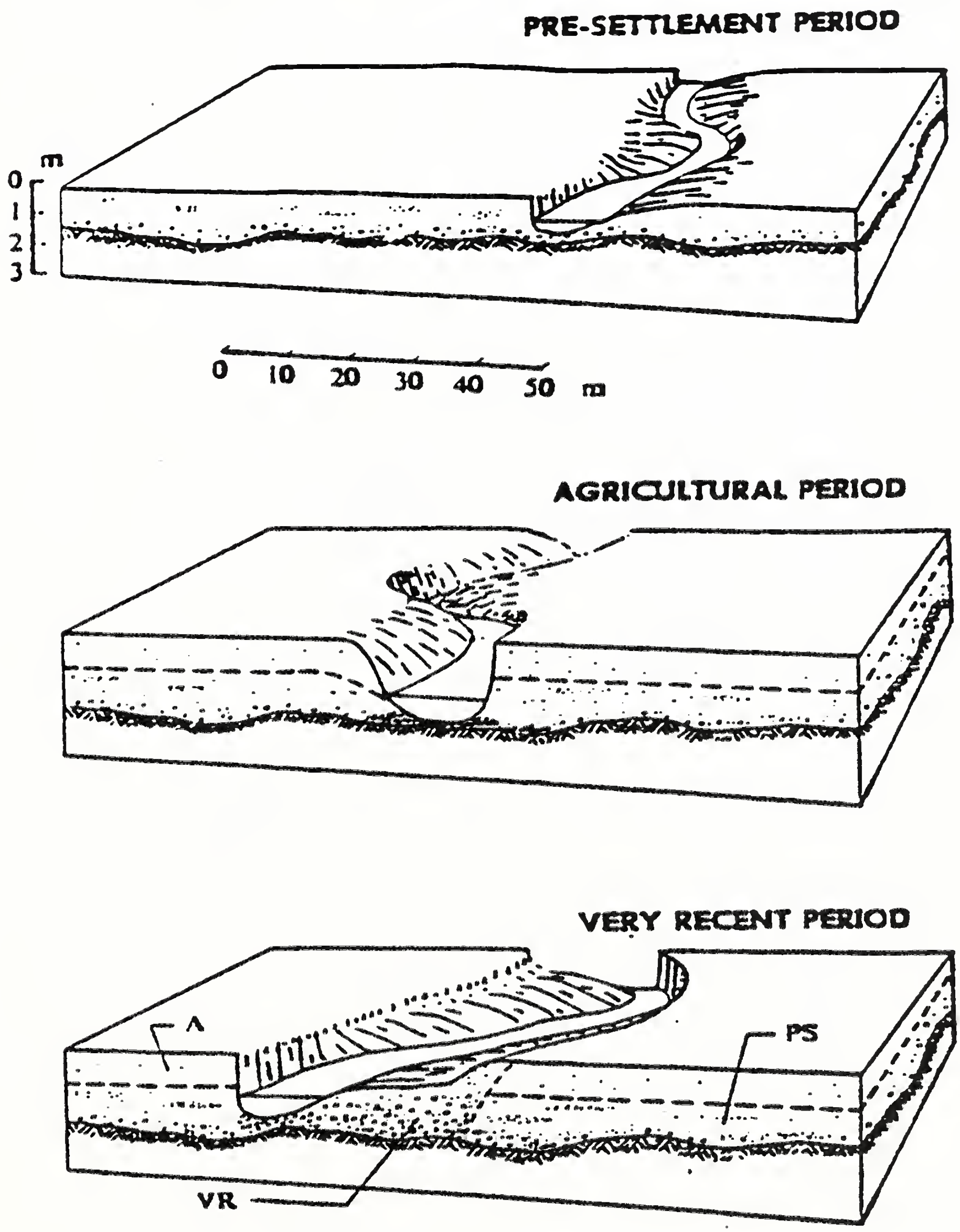


FIGURE VI-12 TYPICAL CROSS-SECTION OF A COLLUVIAL/ALLUVIAL REACH.

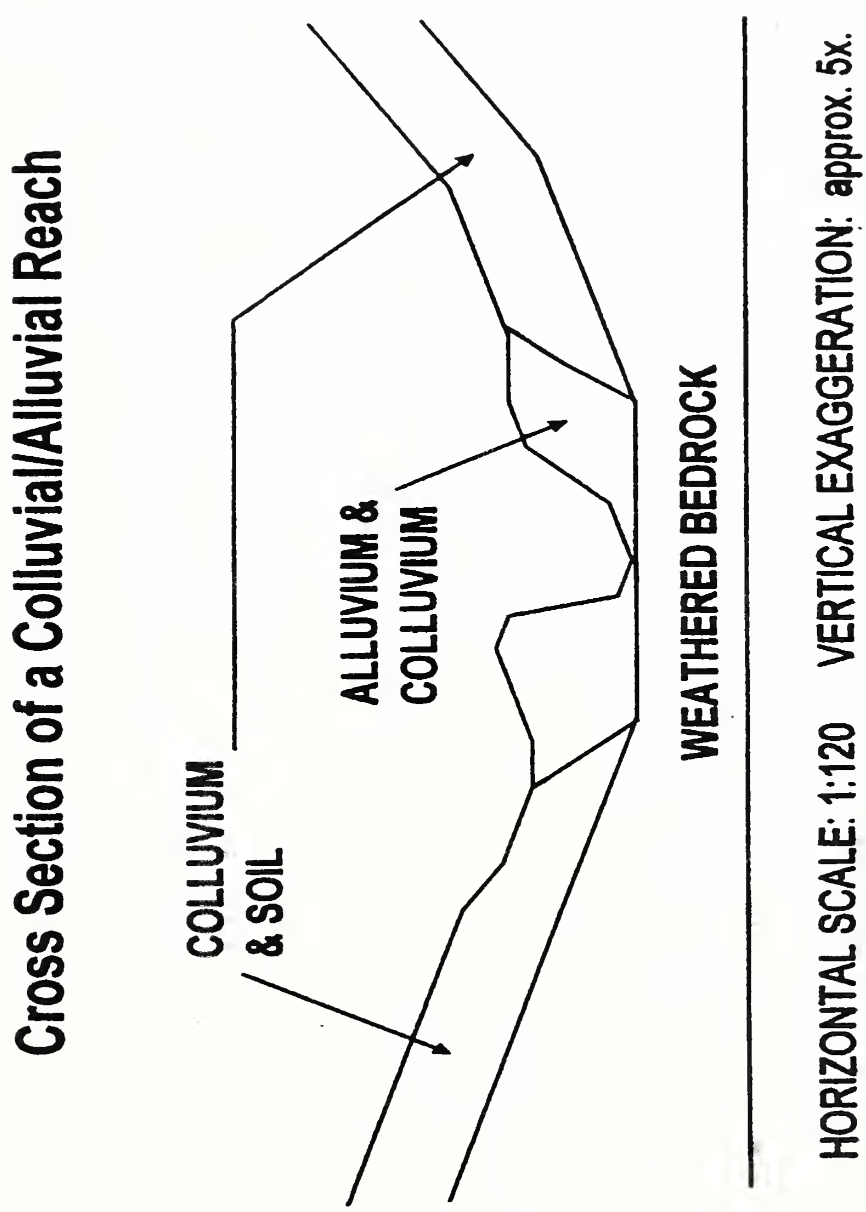
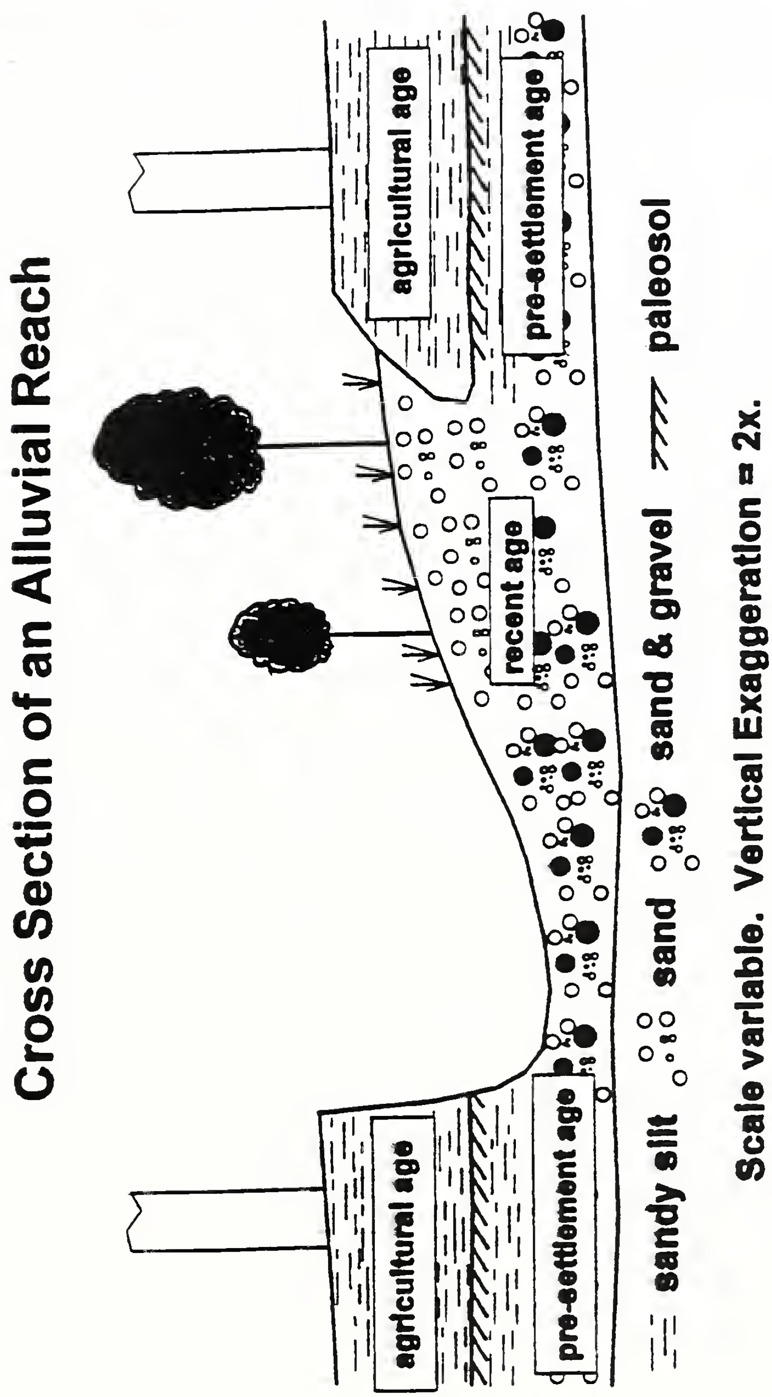


FIGURE VI-11 TYPICAL CROSS-SECTION OF AN ALLUVIAL REACH.



STREAM CLASSIFICATION

Stream classification provides a way to look at stream channels, letting you group those that are similar or identify features that are different. Since we expect streams of similar type to act in similar ways, classification offers a powerful tool for selecting streams for comparison.

Of the various useful classifications that exist, the system developed by D.L. Rosgen is most commonly used by USDA Forest Service hydrologists.

Rosgen (1994) intends his classification to allow

- prediction of a river's behavior from its appearance;
- comparison of site-specific data from a given reach to data from other reaches of similar character; and
- a consistent and reproducible system of technical communication for river studies across a range of disciplines.

Rosgen's classification scheme initially sorts streams into the major, broad stream types (A-G) at a landscape level, as shown in figure 1. At this level, the system classifies streams from headwaters to lowlands with stream type:

A — headwater

B — intermediate

C & E — meandering

D — braided

F — entrenched

G — gully

The Rosgen system breaks stream types into subtypes based on slope ranges (fig. 2) and dominant channel material particle sizes (fig. 3). Subtypes are assigned numbers corresponding to the median particle diameter of channel materials:

1 = bedrock

2 = boulder

3 = cobble

4 = gravel

5 = sand

6 = silt/clay

This produces 41 major stream types. The above oversimplifies the Rosgen system, which includes additional parameters (see table 1, page 6). For more complete information about the classification and associated inventory procedures, see Rosgen (1994). Ultimately, stream classification helps to distinguish variations due to stream type from variations in the state or condition of sites.

Stream variables adjust continuously both through time and along the channel. Usually, one perfect stream type does not yield at a certain point to the next perfect type; the changes are continuous rather than sharply bounded. Recalling the stream continuum concept during classification helps resolve problems that arise when one parameter is outside the range for the stream type implied by the majority of parameters considered.

The decision that must be made at this point is whether to undertake a comprehensive inventory or to select a few representative watersheds. This depends on the concerns driving the data collection process. Long-term processes, such as a Forest Plan revision, an interagency monitoring effort, or an ecosystem management plan, require a deliberate approach to site selection and may include work over several years.

If, on the other hand, an immediate demand for information to support a court brief drives the process, the choice of sites and time may be strictly limited. Short-term measurement, if done to the proper standards, creates a potential

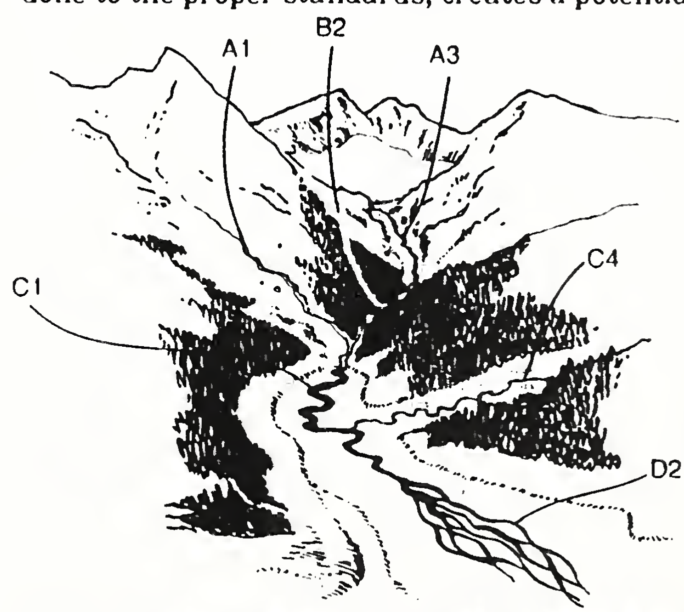


Figure 1. – Stream types in a mountain landscape (adapted from Rosgen 1984). Courtesy of David Rosgen, Wildland Hydrology Consultants.

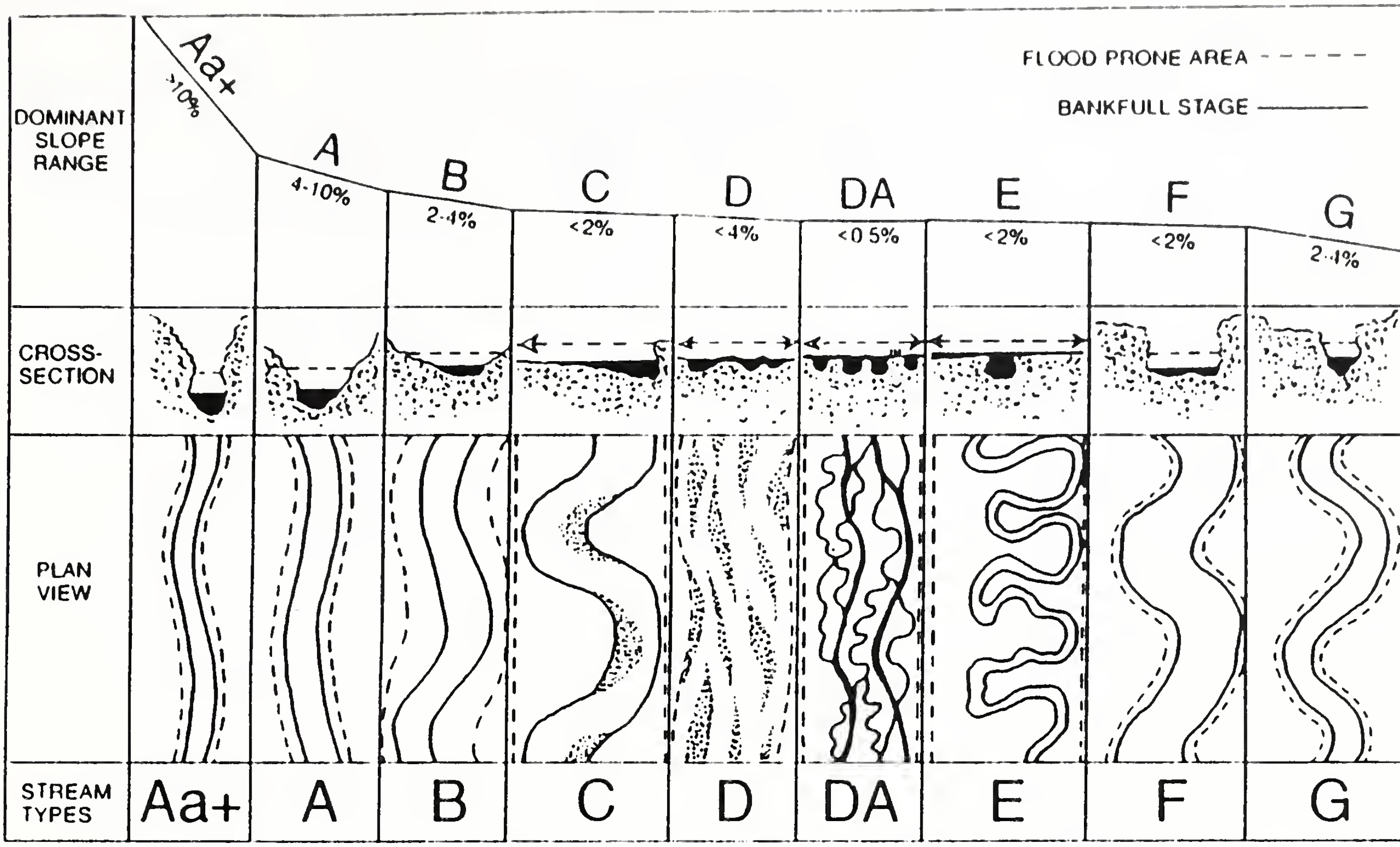
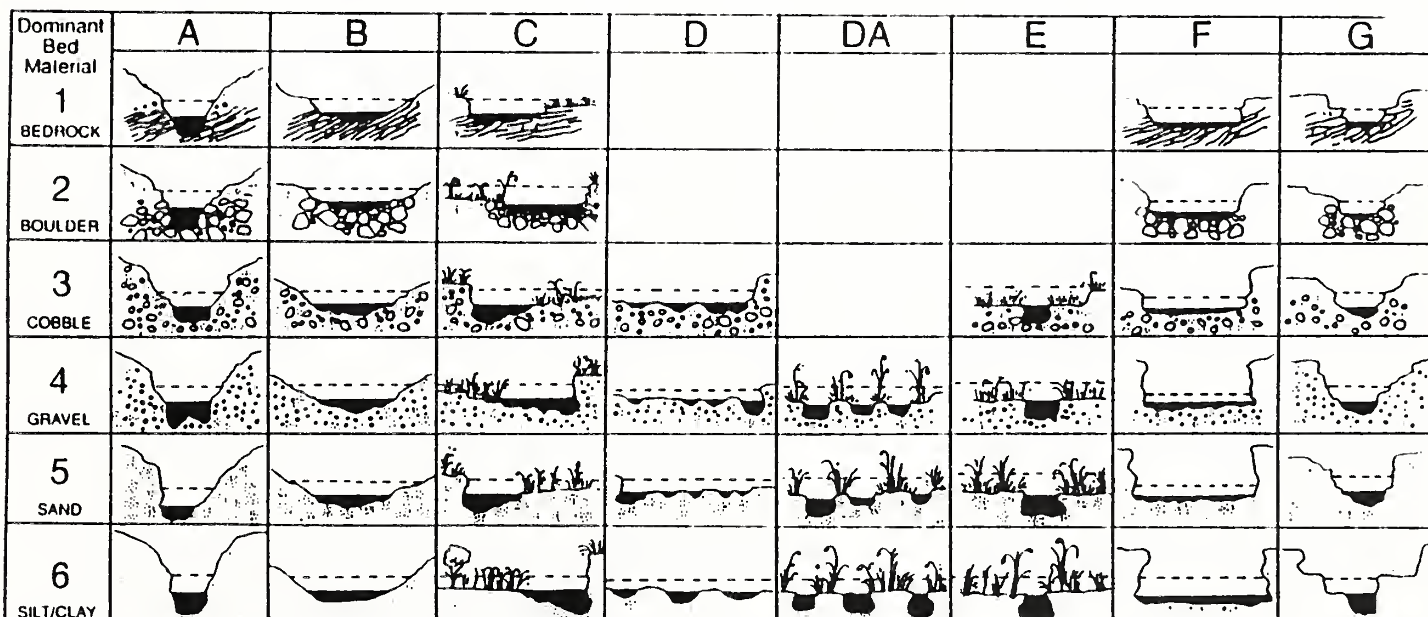


Figure 2. – Stream types: gradient, cross-section, plan view (adapted from Rosgen 1994). Original drawings by Lee Silvey. Courtesy of Calena Verlag.



	A	B	C	D	DA	E	F	G
ENTRH.	<1.4	1.4-2.2	>2.2	N/A	>2.2	>2.2	<1.4	<1.4
SIN.	<1.2	>1.2	>1.4	<1.1	1.1-1.6	>1.5	>1.4	>1.2
W/D	<12	>12	>12	>40	<40	<12	<12	<12
SLOPE	.04-.099	.02-.039	<.02	<.04	<.005	<.02	<.02	.02-.039

Figure 3. – Cross-section view of stream types (adapted from Rosgen 1994). Original drawings by Lee Silvey. Courtesy of Calena Verlag.

Table 1. - Summary of delineative criteria for broad level classification (adapted from Rosgen 1994). Courtesy of Catena Verlag.

Stream Type	General Description	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Landform/Soils/Features
Aa+	Very steep, deeply entrenched, debris transport streams.	<1.4	<12	1.0 to 1.1	>0.10	Very high relief. Erosional, bedrock or depositional features; debris flow potential. Deeply entrenched. Vertical steps with deep scour pools and waterfalls.
A	Steep, entrenched, cascading step-pools. High-energy debris transport assoc. with depositional soils. Very stable if channel dominated by bedrock or boulders.	<1.4	<12	1.0 to 1.2	0.04 to 0.10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined with cascading reaches. Frequently-spaced, deep pools in assoc. step-pool bed morphology.
B	Moderately entrenched, moderate-gradient, riffle-dominated channel with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4 to 2.2	>12	>1.2	0.02 to 0.039	Moderate relief, colluvial deposition and/or residual soils. Moderate entrenchment and W/D ratio. Narrow, gently sloping valleys. Rapids predominate with occasional pools.
C	Low-gradient, meandering, alluvial riffle-pool, channels with point bars. Broad, well-defined floodplains.	>2.2	>12	<1.4	<0.02	Broad valleys with terraces in assoc. with floodplains alluvial soils. Slight entrenchment with well-defined meanders. Riffle/pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channels with eroding banks.	n/a	>40	n/a	<0.04	Broad valleys with alluvial and colluvial fans. Glacial debris and depositional features. Active lateral adjustment with abundant sediment supply.
DA	Multiple channels, narrow and deep with expansive, vegetated floodplain and wetlands. Very gentle relief, highly variable sinuosity. Stable stream banks.	>4.0	<40	variable	<0.005	Broad, low-gradient valleys with fine alluvium and/or lacustrine soil. Multiple-channel geologic-control creating fine deposition with well-vegetated, laterally-stable bars. Broad floodplains and wetlands.
E	Low-gradient, meandering, riffle/pool stream with low W/D ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<0.02	Broad valley/meadows. Alluvial materials with floodplain. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology, very low W/D ratio.
F	Entrenched, meandering riffle/pool channel, of low gradient, with high width/depth ratio.	<1.4	<12	1.4	<0.02	Entrenched in highly weathered material. Low-gradient, with high W/D ratio. Meandering, laterally unstable with high bank erosion. Riffle/pool bed.
G	Entrenched, "gully" step-pool channel, on moderate gradients, with low width/depth ratio.	<1.4	<12	>1.2	0.02 to 0.039	Narrow valley, or deeply incised in alluvial or colluvial material (i.e., fans or deltas). Unstable, with grade control problems and high rates of bank erosion. Gully, step-pool bed.

for further collection of data. Thus, a short-term concern (such as a water-rights case) provides an opportunity to establish permanent reference sites that can be useful for many years in a variety of other contexts.

This long-term potential makes quality field work essential. A well-placed site, with accurate and fully documented measurements, has value extending far into the future. When the boulders are slick, and your waders leak, and the mosquitoes form clouds around your head as you take survey notes, it helps to think of your work as part of a lasting legacy.

FINAL SITE SELECTION

Once a stream has been selected, locate a site for the monumented cross-section and longitudi-

nal survey in the field before starting your survey measurements.

The measurement techniques in this document apply to wadable streams. If your target stream is too high during peak runoff, you can still establish a benchmark, shoot elevations at the water's edge, and mark indicators of stream stage with pin-flags. Schedule the remainder of the field work for low-water periods.

For a general-purpose reference site, the best practice is to avoid sites with evident impacts and to fully document any factors on or near the site that influence stream character.

1. Choose sites with evident natural features. Features of most interest include those involved in developing and maintaining the channel, floodplains, terraces, bars, and natural vegetation.
2. Look for evidence of physical impact on the stream, banks, or in the floodplain from fords, roads, bridges, buildings, diversions, dams, habitat structures, etc. — unless your purpose includes studies of the effects of road encroachment, culverts, regulated flows (dams, diversions), heavy livestock use, and highly impacted watersheds (high road density, high levels of soil disturbance).
3. The reach should include an entire meander (*i.e.,* two bends) if possible. The length should be at least 20 times the bankfull width of the channel. Given the fairly constant relation between the width of the channel, the radii of meander bends, and the sequence of pools and riffles, this length will include a range of features sufficient to accurately characterize the stream. Unless your purpose includes studies of beaver dams, debris jams, boulder fields, bedrock controls, and recently adjusted channels (flood, disturbance), select your site to avoid such features.
4. Locate the monumented cross-section on a straight segment between two bends. This is the best location for the repeated measurements of discharge needed to generate a rating curve.
5. Access should be *possible* with the necessary tools (level, rod, waders, etc.) yet not so easy that there are tire tracks and firepits all over the floodplain. Good locations are a compromise between the comfort of the hydrologist and the long-term integrity of the site. Use your *best* scientific instinct.

Placing of a complete reference site usually requires a full day, with a follow-up visit likely. Finishing calculations, plotting, and documenting the site generally require another day of office work.

The following sections of this manual describe field procedures in the logical progression of field work normally required to establish a permanent reference site. The first step in that process is mapping the location of the study site. The next two sections discuss mapping standards to permanently document the location of the site for future reference.

7. Floodplain and Bankfull Indicators

Using the basic survey techniques covered in the previous chapter, you can accurately quantify and map the major features of a stream channel and the surrounding landscape it has formed. The benchmark you establish is a permanent reference point for the survey. The next questions are: What natural features should be measured and mapped? Where do you set the rod?

Some valuable indicators of stream character, such as the edges of the water and the channel bottom, are easy to locate. Yet others of equal importance, such as bankfull discharge, and the boundaries of the active floodplain, are harder to define. If you observe the stream at bankfull discharge, the water level will be obvious, but this discharge is infrequent. The average discharge, which you are more likely to encounter, fills about 1/3 of the channel, and is reached or exceeded only 25% of the time (Leopold 1994).

Bankfull discharge largely controls the form of alluvial channels. It closely corresponds to the effective discharge or to the flow that transports the largest amount of sediment in the long-term under current climatic conditions and may be thought of as the channel maintaining flow. "Bankfull discharge is defined as that water discharged when stream water just begins to overflow into the active floodplain; the active floodplain is defined as a flat area adjacent to the channel constructed by the river and overflowed by the river at a recurrence interval of about 2 years or less" (Wolman and Leopold 1957).

Erosion, sediment transport, and bar building by deposition are most active at discharges near bankfull. The effectiveness of higher flows—called overbank or flood flows—does not increase proportionally to their volume above bankfull, since overflow into the floodplain distributes the energy of the stream over a greater area.

Finding indicators of bankfull stage (or elevation) in order to calculate stream discharge is crucial, but this may be difficult in the field. Stream-types and indicators vary, and the process requires many separate judgments; a lack of consistency by a single person or among several people can yield poor results.

The active floodplain is the flat, depositional surface adjacent to many stream channels. It is the best indicator of bankfull stage. Floodplains are most prominent along low-gradient, meandering reaches (e.g., Rosgen's type C channel). They are often hard or impossible to identify along steeper mountain streams (Rosgen's types A and B). They may be intermittent on alternate sides of meander bends or may be completely absent. Steep, confined streams in rocky canyons often lack distinguishable floodplains, so other features must be used (Emmett 1975). Recently disturbed systems may give false indications of bankfull.

Where floodplains are absent or poorly defined, other indicators may serve as surrogates to identify bankfull stage. The importance of specific indicators varies with stream type. Several indicators should be used to support identification of the bankfull stage; use as many as can be found. Useful indicators include

- the height of depositional features (especially the top of the pointbar, which defines the lowest possible level for bankfull stage);
- a change in vegetation (especially the lower limit of perennial species);
- slope or topographic breaks along the bank;
- a change in the particle size of bank material, such as the boundary between coarse cobble or gravel with fine-grained sand or silt;
- undercuts in the bank, which usually reach an interior elevation slightly below bankfull stage; and
- stain lines or the lower extent of lichens on boulders.

When measuring indicators of stream stage, set the rod on a stable surface at the level of the indicator. Use pin-flags to mark these points if necessary. Flags are useful if an error leads to a re-survey or if there are dubious points on your field plots requiring discussion and further measurement. Observers need to correlate these indicators to flow measurement at gages and integrate several factors.

INDICATORS OF BANKFULL STAGE

Common bankfull indicators include (figs. 42, 43, 44, and 45):

1. TOP OF POINTBARS. The pointbar consists of channel material deposited on the inside of meander bends. They are a prominent feature of C-type channels but may be absent in other types. Record the top elevation of pointbars as the lowest possible bankfull stage since this is the location where the floodplain is being constructed by deposition.
2. CHANGE IN VEGETATION. Look for the low limit of perennial vegetation on the bank, or a sharp break in the density or type of vegetation. On surfaces lower than the floodplain, vegetation is either absent or annual. During a series of dry years, such as 1985-1990 in much of the western United States, perennial plants may invade the formerly active floodplain. Catastrophic flows may likewise alter vegetation patterns. On the floodplain (above bankfull stage) vegetation may be perennial but is generally limited to typical stream side types. Willow, alder, or dogwood often form lines near bankfull stage. The lower limit of mosses or lichens on rocks or banks, or a break from mosses to other plants, may help identify bankfull stage.
3. CHANGE IN SLOPE. Changes in slope occur often along the cross-section (e.g., from vertical to sloping, from sloping to vertical, or from vertical or sloping to flat at the floodplain level). The change from a vertical bank to a horizontal surface is the best identifier of the floodplain and bankfull stage, especially in low-gradient meandering streams. Many banks have multiple breaks, so be careful and examine banks at several sections of the selected reach for comparison. Slope breaks also mark the extent of stream terraces, which may be measured and mapped in your survey. Terraces are old floodplains that have been abandoned by a downcutting stream. They will generally have perennial vegetation, definite soil structure, and other features to distinguish them from the active floodplain. Most streams have three distinct terraces at approximately 2 to 4 feet, 7 to 10 feet, and 20 to 30 feet above the present

Figure 42. - Indicators of bankfull stage: pointbars, undercut bank, and change in vegetation.

Figure 43. - Change in bank materials. Lower left side of photo shows transition from large cobble to gravel to silt along stream bank.

stream. Avoid confusing the level of the lowest terrace with that of the floodplain: they may be close in elevation.

4. CHANGE IN BANK MATERIALS. Any clear change in particle size may indicate the operation of different processes (e.g., coarse, scoured gravel moving as bedload in the active channel giving way to fine sand or silt deposited by overflow). Look for breaks from coarse, scoured, water-transported particles to a finer matrix that may exhibit some soil structure or movement. Changes in slope may also be associated with a change in particle size. Change need not necessarily be from coarse-to-fine material but may be from fine-to-coarse.

5. BANK UNDERCUTS. Look for bank sections where the perennial vegetation forms a dense root mat. Feel up beneath this root mat and estimate the upper extent of the undercut. (A pin-flag may be inserted horizontally and located by touch at the upper extent of the undercut as a datum for the rod.) This is usually slightly below bankfull stage. Bank undercuts are best used as indicators in steep channels lacking floodplains. Where a floodplain exists, the surface of the floodplain is a better indicator of bankfull stage than undercut banks that may also exist.

6. STAIN LINES. Look for frequent-inundation water lines on rocks. These may be marked by sediment or lichen. Stain lines are often left by lower, more frequent flows, so bankfull is at or above the *highest* stain line.

Deposits of pine needles, twigs, and other floating materials are common along streams, but they are seldom good indicators of bankfull stage. A receding stream may leave several parallel deposits. Floods may also leave organic drift above bankfull stage.

If stream gage data is available for the stream, observations of indicators at or near the gages may help to identify the indicators most useful for a particular area. Ratios of present-to-bankfull discharge can be used to estimate bankfull stage at nearby sites. Bankfull discharges

Figure 44. – Undercut bank and change in vegetation as indicators of bankfull stage.

Figure 45. – Lichen break.

tend to have similar flow-frequency (approximately 1.5 years) and flow-duration characteristics among sites in a given climatic region. Use this ratio and observations of bankfull stage at local stream gages to test the reliability of the various indicators for your geographic area.

Compare your calculation of bankfull discharge to the regional averages by drainage area. Figure 46 illustrates bankfull dimensions of width, depth, and cross-sectional area for four geographic regions. Use the graphs to validate your selected bankfull stage. If it is unreasonably different, examine your methods.

MARKING INDICATORS OF BANKFULL STAGE

The field determination of bankfull stage is basically detective work. Crew members walk the selected reach and mark probable indicators (using pin flags, flagging tied on shrubs, etc.). This usually involves discussion and even some disagreement as to the significance of individual marks.

Wade the center of the channel to view bankfull stage along both banks. During the process, visualize the water surface at bankfull and note channel features such as bars, boulders, and rootwads that may affect water surface elevation or direct the current. The final test of bankfull indicators is measuring their elevation as part of the survey and plotting a longitudinal profile of bankfull elevation for the entire reach. (See figure 53). A line drawn through the points represents the sloping plane of bankfull flow. Significant scatter of bankfull elevations is normal. Outlying points will be evident and may be rechecked to see what sort of indicators give the most useful and consistent results for the selected reach.

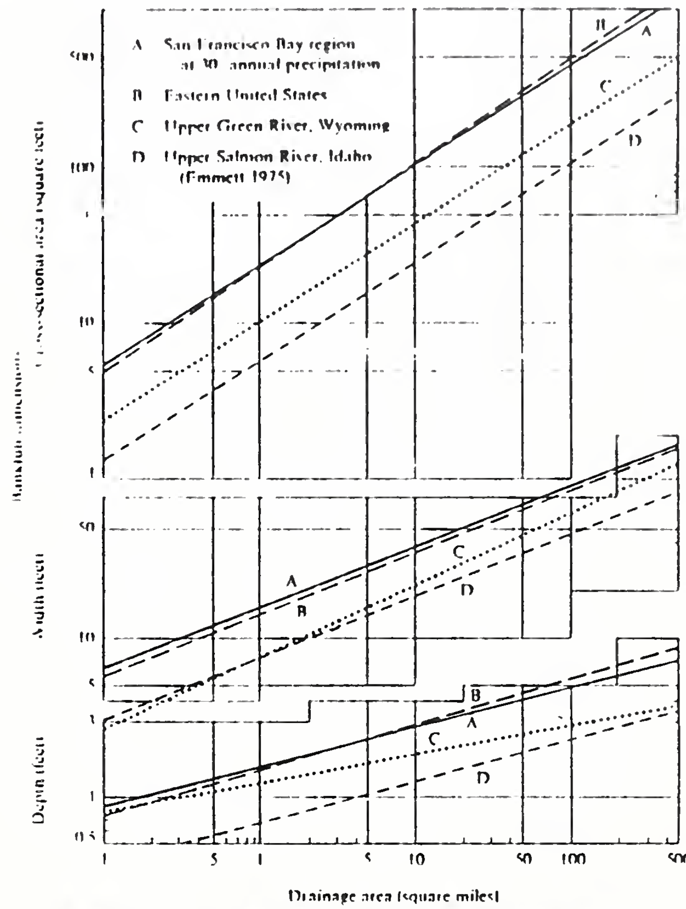


Figure 46. – Average values of bankfull channel dimensions as functions of drainage area for four regions. From: *Water in Environmental Planning* by Thomas Dunne and Luna B. Leopold. Copyright © 1978 by W.H. Freeman and Company. Reprinted with permission.

11. Bed and Bank Material Characterization

The composition of the stream bed and banks is an important facet of stream character, influencing channel form and hydraulics, erosion rates, sediment supply, and other parameters. Each permanent reference site includes a basic characterization of bed and bank material. For studies of fish habitat, riparian ecosystems or stream hydraulics, the characterization of substrates and bank materials may require greater detail than can be covered in this manual.

CHARACTERIZING STREAM BEDS

The composition of the stream bed (substrate) is an important factor in how streams behave. Observations tell us that steep mountain streams with beds of boulders and cobbles act differently from low-gradient streams with beds of sand or silt. You can document this difference with a quantitative description of the bed material, called a pebble count.

The most efficient basic technique is the Wolman Pebble Count (1954). This requires an observer with a metric ruler who wades the stream and a note taker who wades or remains on the bank with the field book.

Particles are tallied by using Wentworth size classes in which the size doubles with each class (2, 4, 8, 16, 32, etc.) or smaller class intervals based on 1/2 phi values (4, 5, 6, 8, 11, 16, 22, 32, etc.).

The latter classes are generally used when detailed particle size data are needed.

Table 2 shows size classes and size ranges. Particles smaller than 2mm in size are placed in a class defined as "<2mm."

Pebble counts can be made using grids, transects, or a random step-toe procedure. A step-toe procedure is used here.

Table 2. - Pebble count size classes.

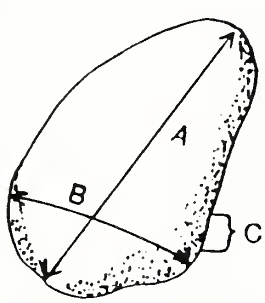
Size Class	Size Range (mm)
Sand	<2
Very Fine Gravel	2-4
Fine Gravel	4-6
Fine Gravel	6-8
Medium Gravel	8-11
Medium Gravel	11-16
Coarse Gravel	16-22
Coarse Gravel	22-32
Very Coarse Gravel	32-45
Very Coarse Gravel	45-64
Small Cobble	64-90
Medium Cobble	90-128
Large Cobble	128-180
Very Large Cobble	180-256
Small Boulder	256-512
Medium Boulder	512-1024
Large Boulder	1024-2048
Very Large Boulder	2048-4096

Pebble Count Procedure

1. Select a reach on or near the cross-section and indicate it on your site map. For stream characterization, sample pools and riffles in the same proportions as they occur in the study reach. For other purposes, it may be appropriate to sample pools and riffles separately. Measure a minimum of 100 particles to obtain a valid count. Use a tally sheet to record the count.
2. Start the transect at a randomly selected point (perhaps by tossing a pebble) at one of the bankfull elevations (not necessarily the present water level). Averting your gaze, pick up the first particle touched by the tip of your index finger at the toe of your wader (fig. 59).
3. Measure the intermediate axis (neither the longest nor shortest of the three mutually perpendicular sides of each particle picked up) (fig. 60 and 61). Measure embedded particles or those too large to be moved in place. For these, measure the smaller of the two exposed axes. Call out the measurement. The note taker tallies it by size class and repeats it back for confirmation.

Figure 59. - Picking up pebble.

Figure 61. - Measuring intermediate axes.



A = LONGEST AXIS (LENGTH)

B = INTERMEDIATE AXIS (WIDTH)

C = SHORTEST AXIS (THICKNESS)

Figure 60. - Intermediate axes of pebble.

4. Take one step across the channel in the direction of the opposite bank and repeat the process, continuing to pick up particles until you have the requisite number (100 or more) of measurements. The note taker keeps count. Traverse across the stream perpendicular to the flow. Continue your traverse of the cross-section until you reach an indicator of bankfull stage on the opposite bank so that all areas between the bankfull elevations are representatively sampled. You may have to duck under bank-top vegetation or reach down through brush to get an accurate count. Move upstream or downstream randomly or at a predetermined distance and make additional transects to sample a total of at least 100 particles.

After counts and tallies are complete, plot the data by size class and frequency (fig. 62).

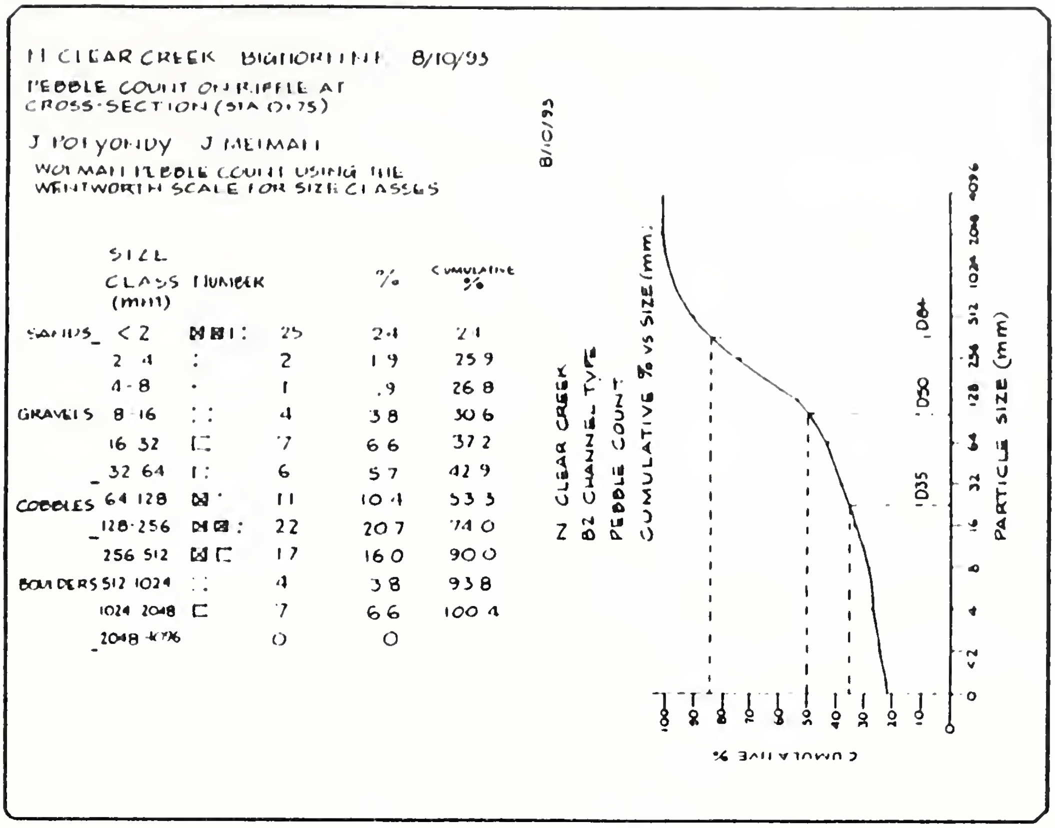


Figure 62. – Field plot of pebble count.

Scour Chains

Scour chains may be used to measure the aggradation or degradation of the stream bed. Place a standard length of chain or abrasion-resistant cord vertically into the bed material with the lower end anchored to a horizontal pin below the estimated extent of scouring. The loose end should drape over the bed surface (fig. 63).

Install scour chains at a surveyed cross-section, at intervals according to channel width and complexity (generally 5 to 10 chains per cross-section). Measure and record (along with a tape measurement of the length of chain left exposed, if any) the elevation of the lower end of each chain and the present elevation of the bed material. Excavate chains after peak flow events and repeat measurement of the chains along with a survey of the cross-section. A kink or bend in a buried chain indicates scouring and reburial. (For more information see Gordon 1992; Lisle and Eads 1991.)

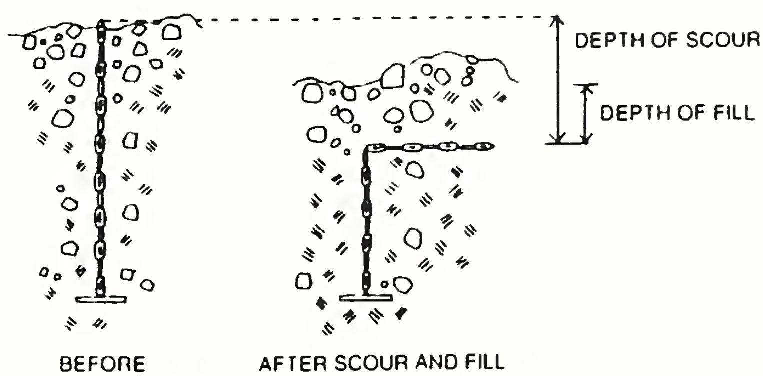


Figure 63. – Scour chains and placement.

CHARACTERIZING STREAM BANKS

Describing the composition and condition of stream banks is an important aspect of monitoring and is best done when streams are at low stage and most of the bank is visible. Describe both banks at the cross-section and other sites as necessary for study purposes. Measure distances upstream or downstream from the cross-section and note sites on your map.

Three techniques for characterizing banks include photographs and notes, sieve analysis, and erosion pins.

Photographs and Notes

For basic documentation, photograph the bank from the channel centerline, at the cross-section. In the field book, record each photograph and write a brief, top-down description of the angle, structure, and bank material. Pebble count transects can be laid out along stream banks and tallied in the conventional way. This technique is generally only usable in coarse bank materials. Detailed description of soils should follow methods in U. S. Soil Conservation Service, *Soil Survey Handbook* (1982) and *Soil Taxonomy* (1975) or subsequent versions. An example of simple notes is given below:

> **LB:** Top, 2.1 ft., willow, eroding soil, a) 4" grey sand; b) 3" mixed red sand and 2-4mm gravel; c) 0.5" black silt or ash; d) 6" 2-4mm gravel. **LEW 2.3 FT.**
>
> **RB: REW** 18.4 ft., 4-8mm gravel grading to 2-4mm gravel; 22.6 ft.- red sand with organic debris; 24.3 ft.- 170°, alternating thin layers of red sand and black silt with new growth *Scirpus spp.*

Reference color slides to the field book volume and page where the bank is described. Consider use of stereo photography for greater analytical detail (Brewer and Berrier 1984).

Sieve Analysis

If detailed information on bank material is needed, take standard 25 lb. soil samples, and sieve and weigh fractions according to methods in U. S. Soil Conservation Service, *Soil Survey Handbook* (1982). Most Forests have one or more soil scientists to provide help with specifics. Transfer the resulting data to the field book and/or place it in the permanent file for the site.

Bank Erosion Pins

Repeated cross-section and longitudinal profile surveys will measure erosive or depositional changes in banks, but smaller changes may be registered by using bank erosion pins. These are fine metal rods (1/16" - 1/8" x 4" - 12" long) inserted horizontally at regular intervals into a stream bank, leaving a standard length exposed. Measure the elevation of each pin with a rod and level.

On successive visits to the site, measure the exposure of each pin and record it, then drive exposed pins into the bank. If pins are entirely lost, make a note and insert another pin at the same elevation. Figure 64 shows a diagram of erosion pins and placement.

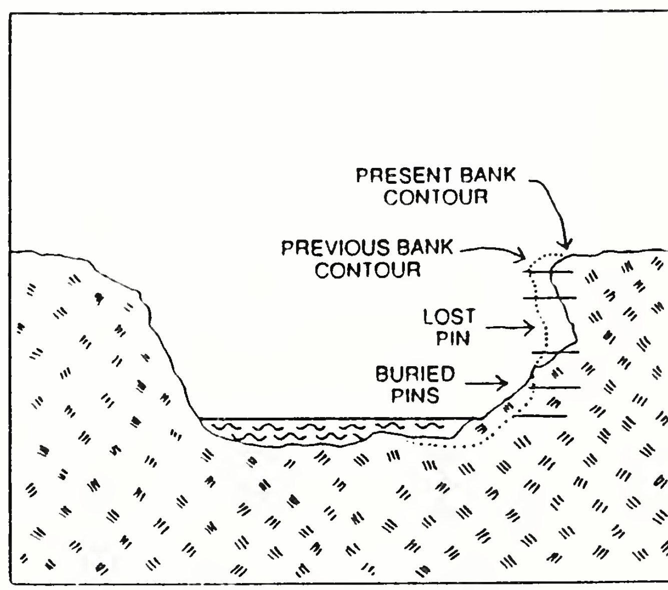


Figure 64. – Bank erosion pins.

HABITAT ASSESSMENT

ROCKY BOTTOM STREAMS

Habitat Parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
1. Attachment Sites for Macroinvertebrates (see page 1, no. 1)	Well-developed riffle and run; riffle is as wide as stream and length extends two times the width of stream; cobble predominates; boulders and gravel common.	Riffle is as wide as stream but length is less than two times width; cobble less abundant; boulders and gravel common.	Run area may be lacking; riffle not as wide as stream and its length is less than 2 times the stream width; gravel or large boulders and bedrock prevalent; some cobble present.	Riffles or run virtually nonexistent; large boulders and bedrock prevalent; cobble lacking.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Embeddedness (see page 1, no. 2)	Fine sediment surrounds and fills in 0-25% of the living spaces around and in between the gravel, cobble, and boulders.	Fine sediment surrounds and fills in 25-50% of the living spaces around and in between the gravel, cobble, and boulders.	Fine sediment surrounds and fills in 50-75% of the living spaces around and in between the gravel, cobble, and boulders.	Fine sediment surrounds and fills in more than 75% of the living spaces around and in between the gravel, cobble, and boulders.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Shelter for Fish (see page 1, no. 3)	Snags, submerged logs, undercut banks, or other stable habitat are found in over 50% of the site.	Snags, submerged logs, undercut banks, or other stable habitat are found in over 30-50% of the site.	Snags, submerged logs, undercut banks, or other stable habitat are found in over 10-30% of the site.	Snags, submerged logs, undercut banks, or other stable habitat are found in less than 10% of the site
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Channel Alteration (see page 1, no. 4)	Stream straightening, dredging, artificial embankments, dams or bridge abutments absent or minimal; stream with meandering pattern.	Some stream straightening, dredging, artificial embankments or dams present, usually in area of bridge abutments; no evidence of recent channel alteration activity.	Artificial embankments present to some extent on both banks; and 40 to 80% of stream site straightened, dredged, or otherwise altered.	Banks shored with gabion or cement; over 80% of the stream site straightened and disrupted
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Sediment Deposition (see page 2, no. 5)	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from coarse gravel; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, coarse sand on old and new bars; 30-50% of the bottom affected; sediment deposits at stream obstructions and bends; moderate deposition in pools.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom affected; pools almost absent due to substantial sediment deposition.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Category: Optimal	Suboptimal	Marginal	Poor
6. Stream velocity and depth combinations (see page 2, no. 6)	slow (< 1 ft/sec)/shallow (< 1ft); slow/deep; fast/deep, fast/shallow all four combinations present	3 of the 4 velocity/depth combinations preset; fast current areas generally predominate.	Only 2 of the 4 velocity/depth combinations are present Score lower if fast current areas are missing	Dominated by 1 velocity/depth category (usually slow/shallow areas)
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Channel Flow Status (see page 2, no. 7)	Water reaches base of both lower banks and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; <25% of channel substrate is exposed	Water fills 25-75% of the available channel and/or riffle substrates are mostly exposed	Very little water in channel and mostly present as standing pools
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Vegetative Protection (score each bank) (see page 3, no. 8) Note: determine left or right side by facing downstream	More than 90% of the streambank surfaces covered by natural vegetation, including trees, shrubs, or other plants; vegetative disruption, through grazing or mowing, minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by natural vegetation, but one class of plants is not well-represented; some vegetative disruption evident; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation, patches of bare soil or closely cropped vegetation common, less than one-half of the potential plant stubble height remaining	Less than 50% of the streambank surfaces covered by vegetation, disruption of streambank vegetation is very high, vegetation has been removed to 2 inches or less in average stubble height
SCORE (LB) ____ SCORE (RB) ____	Left Bank 10 9 Right Bank 10 9	8 7 6 8 7 6	5 4 3 5 4 3	2 1 0 2 1 0
9. Condition of Banks (score each bank) (see page 3, no. 9)	Banks stable; no evidence of erosion or bank failure; little potential for future problems.	Moderately stable; infrequent, small areas of erosion mostly healed over.	Moderately unstable; up to 60% of banks in site have areas of erosion; high erosion potential during floods	Unstable, many eroded areas; "raw" areas frequent along straight sections and bends, obvious bank collapse or failure, 60-100% of bank has erosional scars
SCORE (LB) ____ SCORE (RB) ____	Left Bank 10 9 Right Bank 10 9	8 7 6 8 7 6	5 4 3 5 4 3	2 1 0 2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone) (see page 3, no. 10)	Width of riparian zone >50 feet; no evidence of human activities (i.e., parking lots, roadbeds, clear-cuts, mowed areas, or crops) within the riparian zone.	Width of riparian zone 35-40 feet.	Width of riparian zone 20-35 feet.	Width of riparian zone < 20 feet.
SCORE (LB) ____ SCORE (RB) ____	Left Bank 10 9 Right Bank 10 9	8 7 6 8 7 6	5 4 3 5 4 3	2 1 0 2 1 0

Total Score	

Habitat Characteristics Definitions

Use the habitat characteristic (parameter) definitions and guidance that follows when completing the habitat assessment field data form. Rocky-bottom streams (Piedmont Streams) are generally fast moving streams with beds that are made up of gravel/cobbles/boulders in any combination and that have definite riffle areas.

(1) ***Attachment sites for macroinvertebrates*** are essentially the amount of living space or hard substrates (rocks, snags) available for aquatic insects and snails. Many insects begin their life underwater in streams and need to attach themselves to rocks, logs, branches, or other submerged substrates. The greater the variety and number of available living spaces or attachment sites, the greater the variety of insects in the stream. Optimally, there should be a predominance of cobble, and boulders and gravel should be common. The availability of suitable living spaces for macroinvertebrates decreases as cobble becomes less abundant and boulders, gravel, or bedrock become more prevalent.

(2) ***Embeddedness*** refers to the extent to which rocks (gravel, cobble, and boulders) are surrounded by, covered, or sunken into the silt, sand, or mud of the stream bottom. Generally, as rocks become embedded, the living spaces available to macroinvertebrates and fish for shelter, spawning, and egg incubation are decreased.

To estimate the percent of embeddedness, observe the amount of silt or finer sediments overlying and surrounding the rocks. If kicking does not dislodge the rocks or cobbles, they may be greatly embedded. It may be useful to lift a few rocks and observe how much of the rock (e.g., 1/2, 1/3) is darker due to algal growth.

(3) ***Shelter for fish*** includes the relative quantity and variety of natural structures in the stream, such as fallen trees, logs, and branches, large rocks, and undercut banks, that are available to fish for hiding, sleeping, or laying eggs. A wide variety of submerged structures in the stream provide fish with many living spaces; the more living spaces in a stream, the more types of fish the stream can support.

(4) ***Channel alteration*** is basically a measure of large-scale changes in the shape of the stream channel. Many streams in urban and agricultural areas have been straightened, deepened (e.g. dredged), or diverted into concrete channels, often for flood control purposes. Such streams have far fewer natural habitats for fish, macroinvertebrates, and plants than do naturally meandering streams. Channel alteration is present when the stream runs through a concrete channel; when artificial embankments, riprap, and other forms of artificial bank stabilization or structures are present; when the stream is very straight for significant distances; when dams, bridges, and flow altering structures such as combined sewer overflow pipes are present; when the stream is of uniform depth due to dredging, and when other such changes have occurred.

Signs that indicate the occurrence of dredging include straightened, deepened, and otherwise uniform stream channels, and the removal of streamside vegetation to provide access to the stream for dredging equipment.

(5) ***Sediment deposition*** is a measure of the amount of sediment that has been deposited in the stream channel and the changes to the stream bottom that have occurred as a result of the deposition. High levels of sediment deposition create an unstable and continually changing environment that is unsuitable for many aquatic organisms.

Sediments are naturally deposited in areas where the stream flow is reduced, such as pools and bends, or where flow is obstructed. These deposits can lead to the formation of islands, shoals, or point bars (sediments that build up in the stream, usually at the beginning of a meander) or can result in the complete filling of pools. To determine whether or not these sediment deposits are new, look for vegetation growing on them; new sediments will not yet have been colonized by vegetation.

(6) ***Stream velocity and depth combinations*** are important to the maintenance of aquatic communities. Restrictions to normal velocity and/or the filling of pools will affect the organisms living in the stream by reducing the dissolved oxygen that is available and by slowing down the movement of food items. Streams function best when the movement of water continually replenishes the supply of oxygen and food, and does not become stagnant.

Slow velocity is generally described as water moving **less than (<) 1 foot/second**

Fast velocity is generally described as water moving **greater than (>) 1/foot/second**

Shallow water is generally described as **less than (<) 1.5 feet**

Deep water is generally described as **greater than (>) 1.5 feet**

Four general categories of velocity and depth are optimal for benthic macroinvertebrate and fish communities. The best streams will have all four velocity/depth combinations and can maintain a wide variety of aquatic life:

(1) slow, shallow
(2) slow, deep
(3) fast, deep
(4) fast shallow

Depth can be estimated by standing in the stream at various points. If the water level comes to below the bottom of your knee cap, it can be considered shallow. If it reaches above the bottom of your knee cap, consider it deep. Also, you can use the measuring rope to measure the length of your leg to the knee cap to judge depth.

To estimate velocity, use the measuring rope to mark off 10-foot areas of stream in the same general areas where you measured depth. Drop a twig in the stream and count the number of seconds it takes for the stick to travel the 10 feet. Generally it is best to do this in run and pool areas since velocity is difficult to measure in riffles as the twig may get caught up by rocks. Divide 10 by the number of seconds to determine velocity in "feet per second." For example:

> If the twig took 6 seconds to travel the 10 foot distance, then divide 6 seconds into 10 feet, which is equal to 1.4 ft/sec. In this case, the velocity would be considered fast, as it is greater than 1 ft/sec.

Since water in riffle areas tends to have the greatest velocity, you can assume that riffle velocity is faster than velocity in either the run or pool areas you measure.

(7) ***Channel flow status*** is the percent of the existing channel that is filled with water. The flow status will change as the channel enlarges or as flow decreases as a result of dams and other obstructions, diversions for irrigation, or drought. When water does not cover much of the streambed, the amount of living area for aquatic organisms is limited.

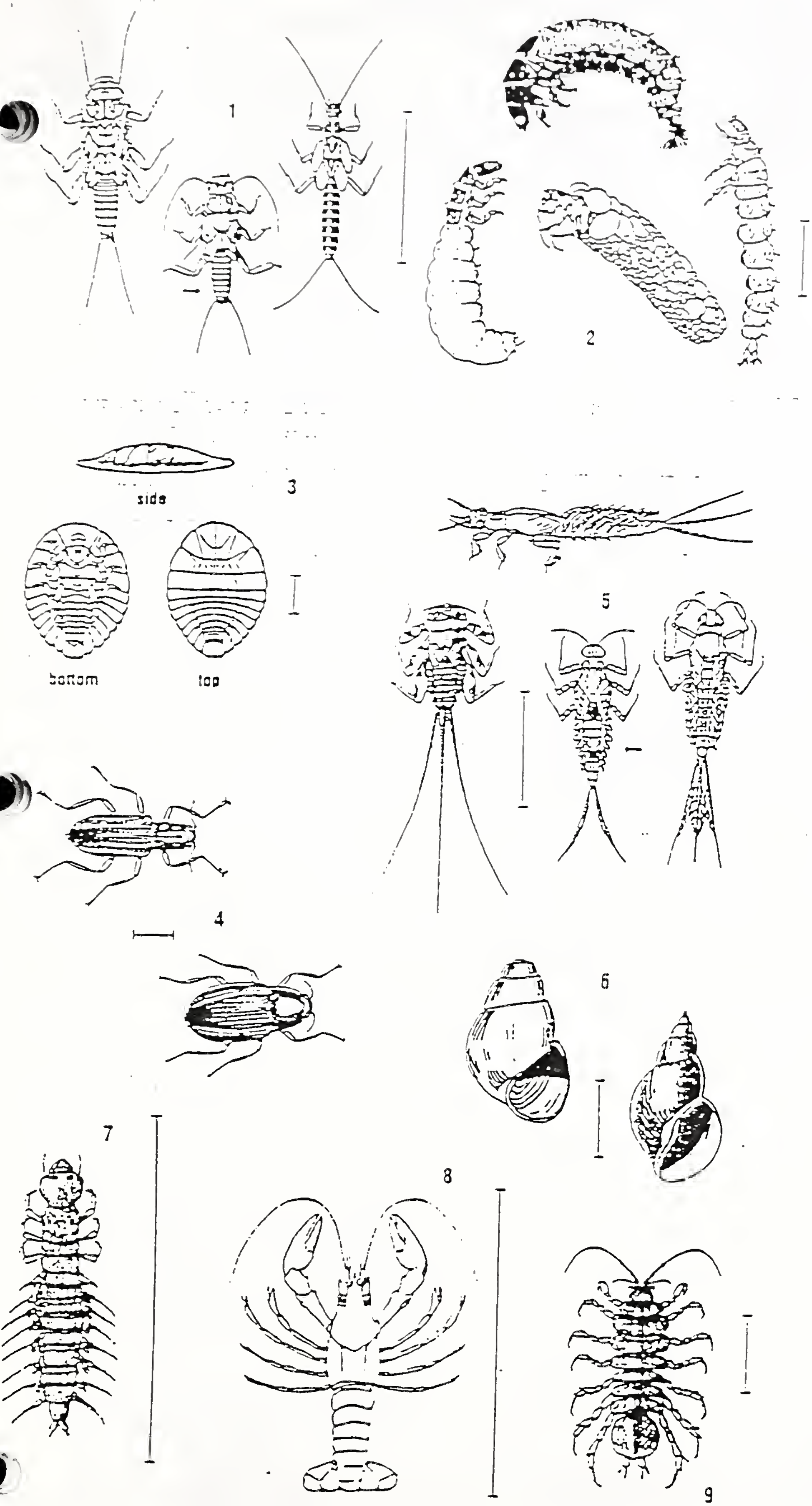
For the last three parameters, take a measure of both the right and left stream banks separately. Determine *left* and *right* by facing downstream.

(8) ***Bank vegetative protection*** measures the amount of the stream bank that is covered by natural (i.e. growing wild and not obviously planted) vegetation. The root systems of plants growing on stream banks help hold soil in place, reducing erosion. Vegetation on banks provides shade for fish and macroinvertebrates, and serves as a food source by dropping leaves and other organic matter into the stream. Ideally, a variety of vegetation should be present, including trees, shrubs, and grasses. Vegetative disruption may occur when the grasses and plants on the stream banks are mowed or grazed upon, or the trees and shrubs are cut back or cleared.

(9) ***Condition of banks*** measures erosion potential and whether the stream banks are eroded. Steep banks are more likely to collapse and suffer from erosion than are gently sloping banks and are therefore considered to have a high erosion potential. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil. Bank failure and the subsequent collapse of portions of the stream bank is referred to as bank sloughing.

(10) ***The riparian vegetative zone width*** is defined here as the width of natural vegetation from the edge of the stream bank. The riparian vegetative zone is a buffer zone to pollutants entering a stream from runoff; it also controls erosion and provides stream habitat and nutrient input into the stream. A wide, relatively undisturbed riparian vegetative zone reflects a healthy stream system; narrow, far less useful riparian zones occur when roads, parking lots, fields, lawns and other artificially cultivated areas, bare soil, rocks, or buildings are near the stream bank. The presence of "old fields" (i.e., previously developed agricultural fields allowed to convert to natural conditions) should rate higher than fields in continuous or periodic use. In arid areas, the riparian vegetative zone can be measured by observing the width of the area dominated by riparian or water-loving plants, such as willows, marsh grasses, and cottonwood trees.

Stream Insects & Crustaceans



Bar lines indicate relative size

GROUP ONE TAXA

Pollution sensitive organisms found in good quality water.

1 *Stonefly: Order Plecoptera.* 1/2" - 1 1/2", 6 legs with hooked tips, antennae, 2 hair-like tails. Smooth (no gills) on lower half of body. (See arrow.)

2 *Caddisfly: Order Trichoptera.* Up to 1", 6 hooked legs on upper third of body, 2 hooks at back end. May be in a stick, rock or leaf case with its head sticking out. May have fluffy gill tufts on lower half.

3 *Water Penny: Order Coleoptera.* 1/4", flat saucer-shaped body with a raised bump on one side and 6 tiny legs on the other side. Immature beetle.

4 *Riffle Beetle: Order Coleoptera.* 1/4", oval body covered with tiny hairs, 6 legs, antennae. Walks slowly underwater. Does not swim on surface.

5 *Mayfly: Order Ephemeroptera.* 1/4" - 1", brown, moving, plate-like or feathery gills on sides of lower body (see arrow), 6 large hooked legs, antennae, 2 or 3 long, hair-like tails. Tails may be webbed together.

6 *Gilled Snail: Class Gastropoda.* Shell opening covered by thin plate called operculum. Shell usually opens on right.

7 *Dobsonfly (Hellgrammite): Family Corydalidae.* 3/4" - 4", dark-colored, 6 legs, large pinching jaws, eight pairs feelers on lower half of body with paired cotton-like gill tufts along underside, short antennae, 2 tails and 2 pairs of hooks at back end.

GROUP TWO TAXA

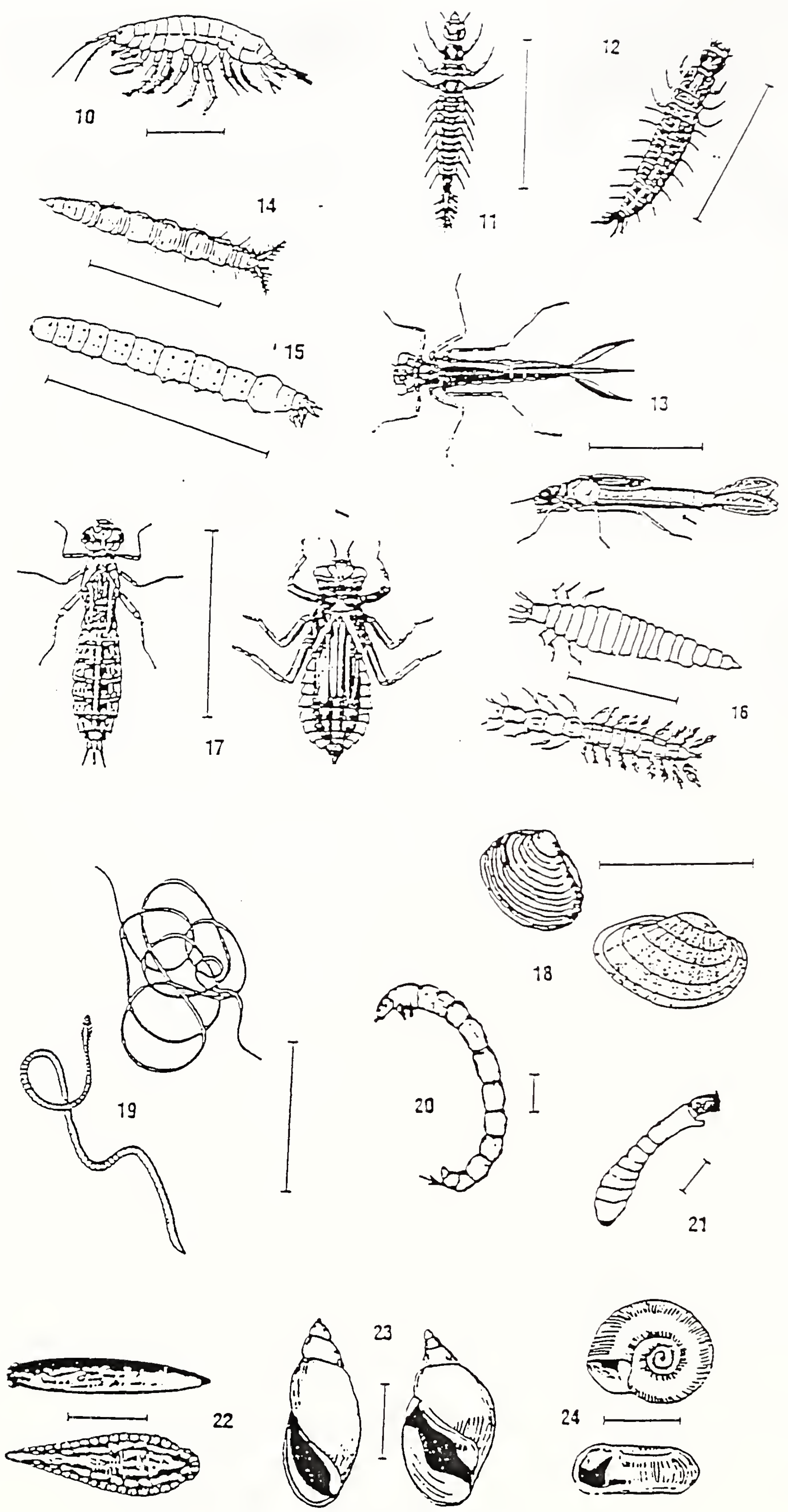
Somewhat pollution tolerant organisms can be in good or fair quality water.

8 *Crayfish: Order Decapoda.* Up to 6", 2 large claws, 8 legs, resembles small lobster.

9 *Sowbug: Order Isopoda.* 1/4" - 3/4", gray oblong body wider than it is high, more than 6 legs, long antennae.

Save Our Streams

Izaak Walton League of America
1401 Wilson Blvd. Level B
Arlington, VA 22209



Bar lines indicate relative size

GROUP TWO TAXA continued

10 *Scud: Order Amphipoda.* 1/4", white to grey, body higher than it is wide, swims sideways, more than legs, resembles small shrimp.

11 *Alderfly larva: Family Sialidae.* 1" long. Looks like small hellgrammite but has 1 long, thin, branched tail at back end (no hooks). No gill tufts underneat

12 *Fishfly larva: Family Corydalidae.* Up to 1 1/2" long. Looks like small hellgrammite but often a lighter reddish-tan color, or with yellowish streaks. No gill tufts underneath.

13 *Damselfly: Suborder Zygoptera.* 1/2" - 1", large eyes, 6 thin hooked legs, 3 broad oar-shaped tails, positioned like a tripod. Smooth (no gills) on sides of lower half of body. (See arrow.)

14 *Watersnipe Fly Larva: Family Athericidae (Atherix).* 1/4" - 1", pale to green, tapered body, many caterpillar-like legs, conical head, feathery "horns" at back end.

15 *Crane Fly: Suborder Nematocera.* 1/3" - 2", milky, green, or light brown, plump caterpillar-like segmented body, 4 finger-like lobes at back end.

16 *Beetle Larva: Order Coleoptera.* 1/4" 1", light-colored, 6 legs on upper half of body, feelers, antennae.

17 *Dragon Fly: Suborder Anisoptera.* 1/2" - 2", lar eyes, 6 hooked legs. Wide oval to round abdom...

18 *Clam: Class Bivalvia.*

GROUP THREE TAXA

Pollution tolerant organisms can be in any quality of water.

19 *Aquatic Worm: Class Oligochaeta.* 1/4" - 2", can be very tiny; thin worm- like body.

20 *Midge Fly Larva: Suborder Nematocera.* Up to 1/4", dark head, worm-like segmented body, 2 tiny legs on each side.

21 *Blackfly Larva: Family Simulidae.* Up to 1/4", one end of body wider. Black head, suction pad on end.

22 *Leech: Order Hirudinea.* 1/4" - 2", brown, slimy body, ends with suction pads.

23 *Pouch Snail and Pond Snails: Class Gastropoda.* No operculum. Breathe air. Shell usually opens on left.

24 *Other snails: Class Gastropoda.* No operculum. Breathe air. Snail shell coils in one plane.

VIRGINIA SAVE OUR STREAMS

Stream Quality Survey

The purpose of this form is to aid you in gathering and recording important data about the health of your stream. By keeping accurate and consistent records of your observations and data from your macroinvertebrate count, you can notice and document changes in water quality. Refer to the SOS insect card and instructions to learn how to trap and identify the organisms.

Stream ______________________ Station ______________________

County ______________________ State ______ Location ______________________

Group or individual ______________________ Number of participants ______________________

Weather conditions ______________________

Stream width (Average) ______ ft. Water depth (In riffle) ______ in.

Flow rate: high ______ low ______ normal ______

You should select a riffle where the water is not running too fast (ideal depth is 3 - 12 inches), and the bed consists of cobble-sized stones or larger.

Monitored riffle area (should be 3 foot square) __________ Average stream depth __________ Water temperature __________

Date ______________________ Time ______________________ Sample Number ______________________

Type of test: macroinvertebrate count _____ chemical test _____ other _____

MACROINVERTEBRATE COUNT

Use the stream monitoring instructions to conduct a macroinvertebrate count. Use letter codes (A = 1 - 9, B = 10 - 99, C = 100 or more) to record the numbers of organisms found in a 3 foot by 3 foot area. Then add up the number of letters in each column and multiply by the indicated index value. The following columns are divided based on the organism's sensitivity to pollution.

SENSITIVE	SOMEWHAT-SENSITIVE	TOLERANT
☐ caddisfly larvae	☐ beetle larvae	☐ aquatic worms
☐ hellgrammite	☐ clams	☐ blackfly larvae
☐ mayfly nymphs	☐ crane fly larvae	☐ leeches
☐ gilled snails	☐ crayfish	☐ midge larvae
☐ riffle beetle adult	☐ damselfly nymphs	☐ pouch (and other) snails
☐ stonefly nymphs	☐ dragonfly nymphs	
☐ water penny larvae	☐ scuds	
	☐ sowbugs	
	☐ fishfly larvae	
	☐ alderfly larvae	
	☐ atherix	
☐ # of letters times 3 = _____ index value +	☐ # of letters times 2 = _____ index value +	☐ # of letters times 1 = _____ index value

Now add together the three index values = _____ total index value.

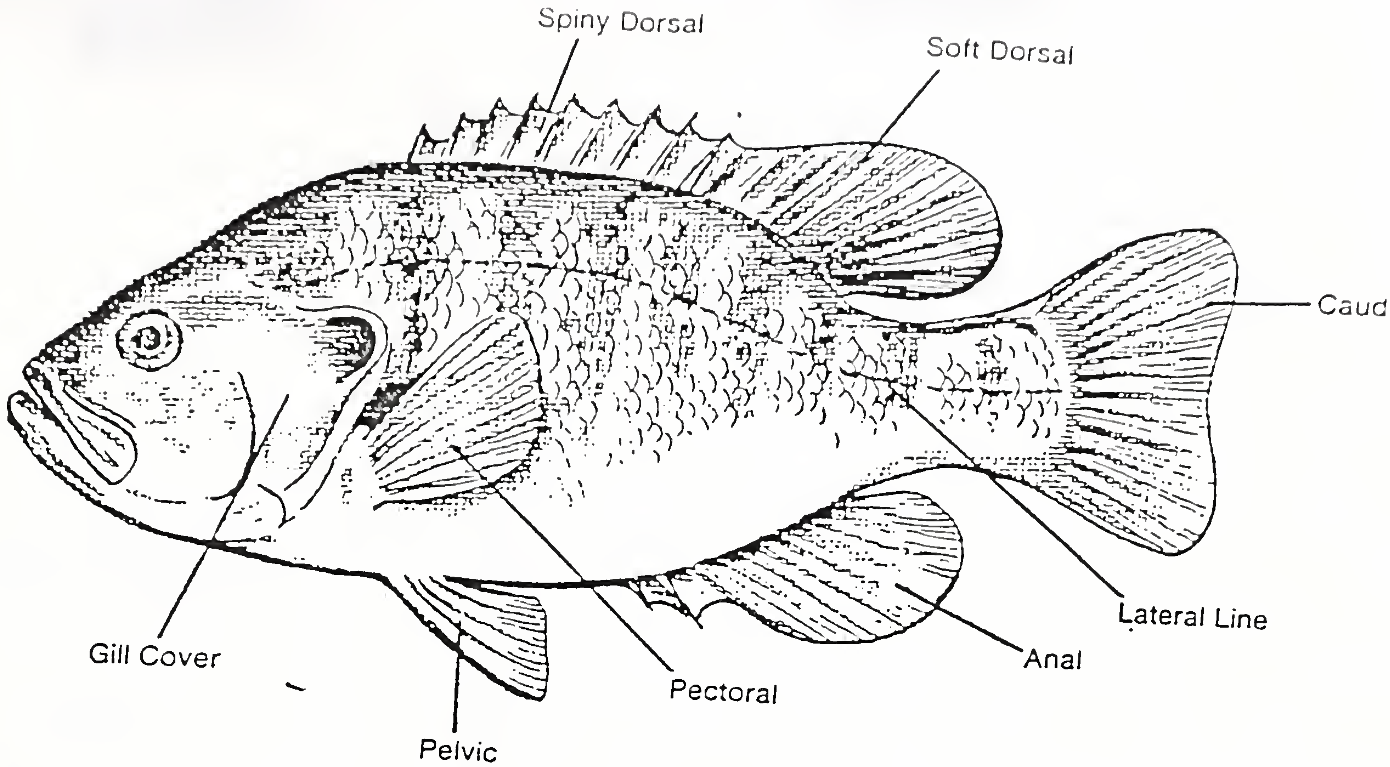
Compare this total index value to the following numbers to determine the water quality of your stream. Good water quality is indicated by a variety of different kinds of organisms, with no one kind making up the majority of the sample.

WATER QUALITY RATING

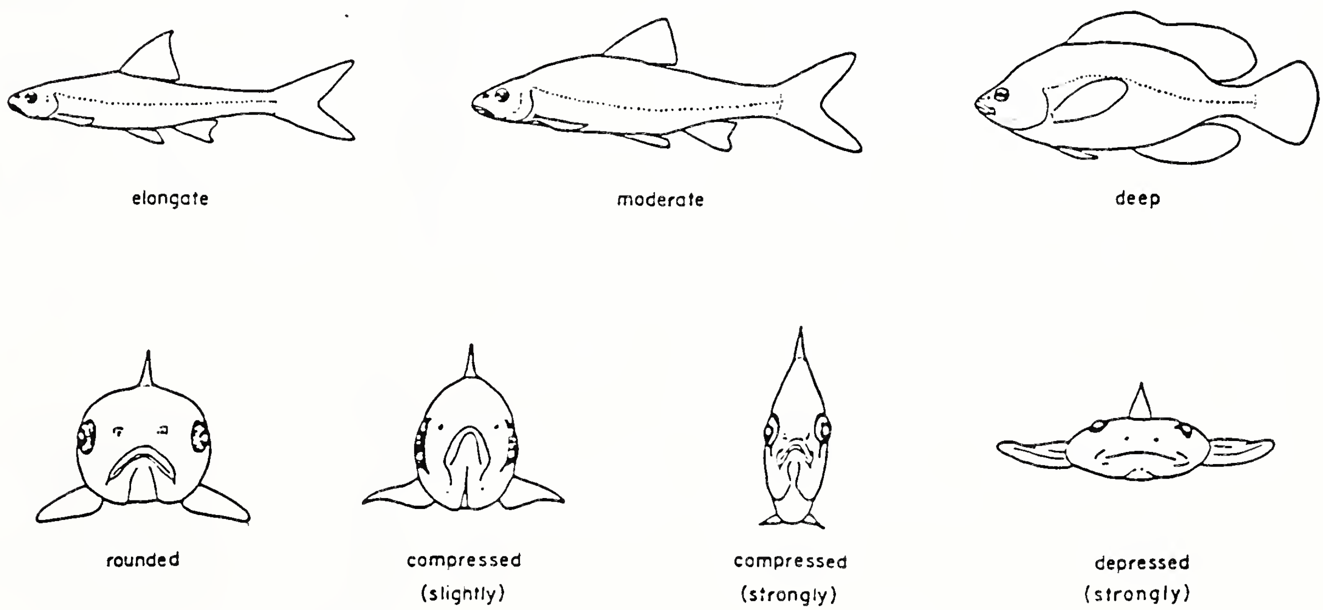
☐ Excellent (> 22) ☐ Good (17 - 22)

☐ Fair (11 - 16) ☐ Poor (< 11)

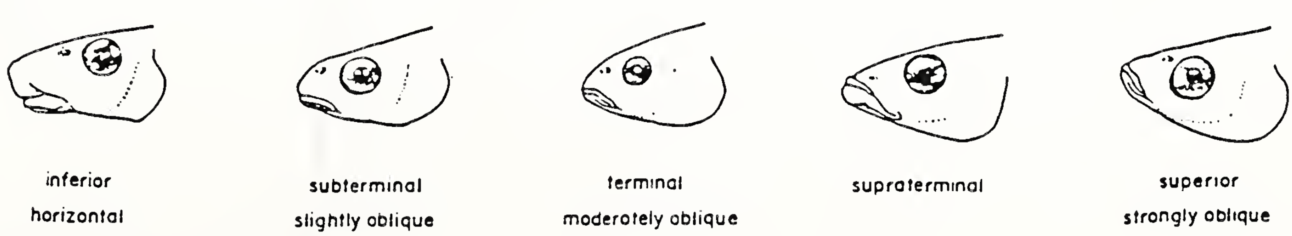
Note: You should test at least 3 different riffles within a 24-foot area to ensure that you have a truly representative sample which includes all key organisms. Record results from the sample which gives the best diversity.



BODY FORMS



MOUTH POSITIONS and ORIENTATIONS



THINGS TO LOOK

BODY SHAPE

COLOR

POSITION O

SIZE OF MO

LIPS

TEETH

GILL RAK

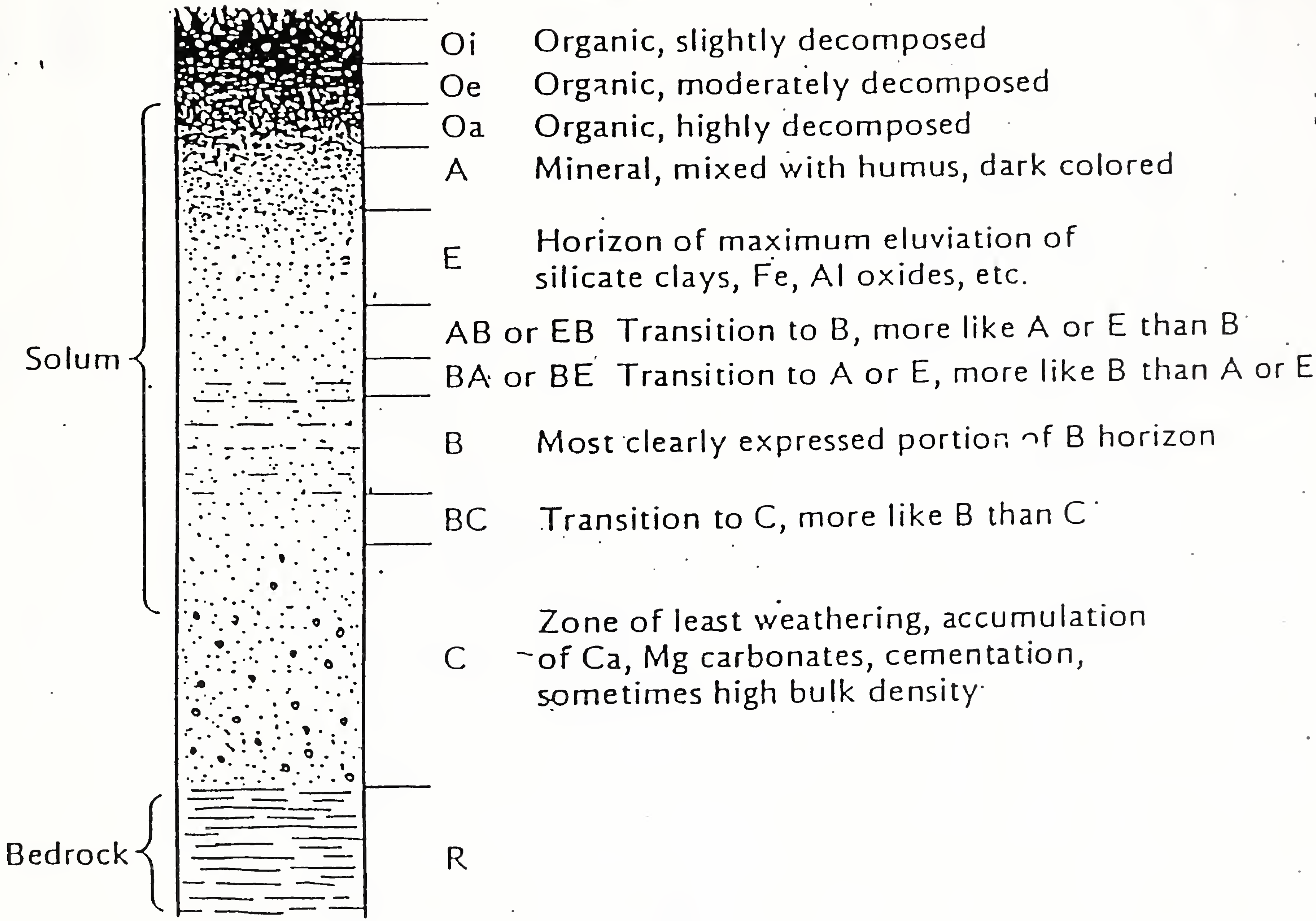
DOES IT

LOCATIO

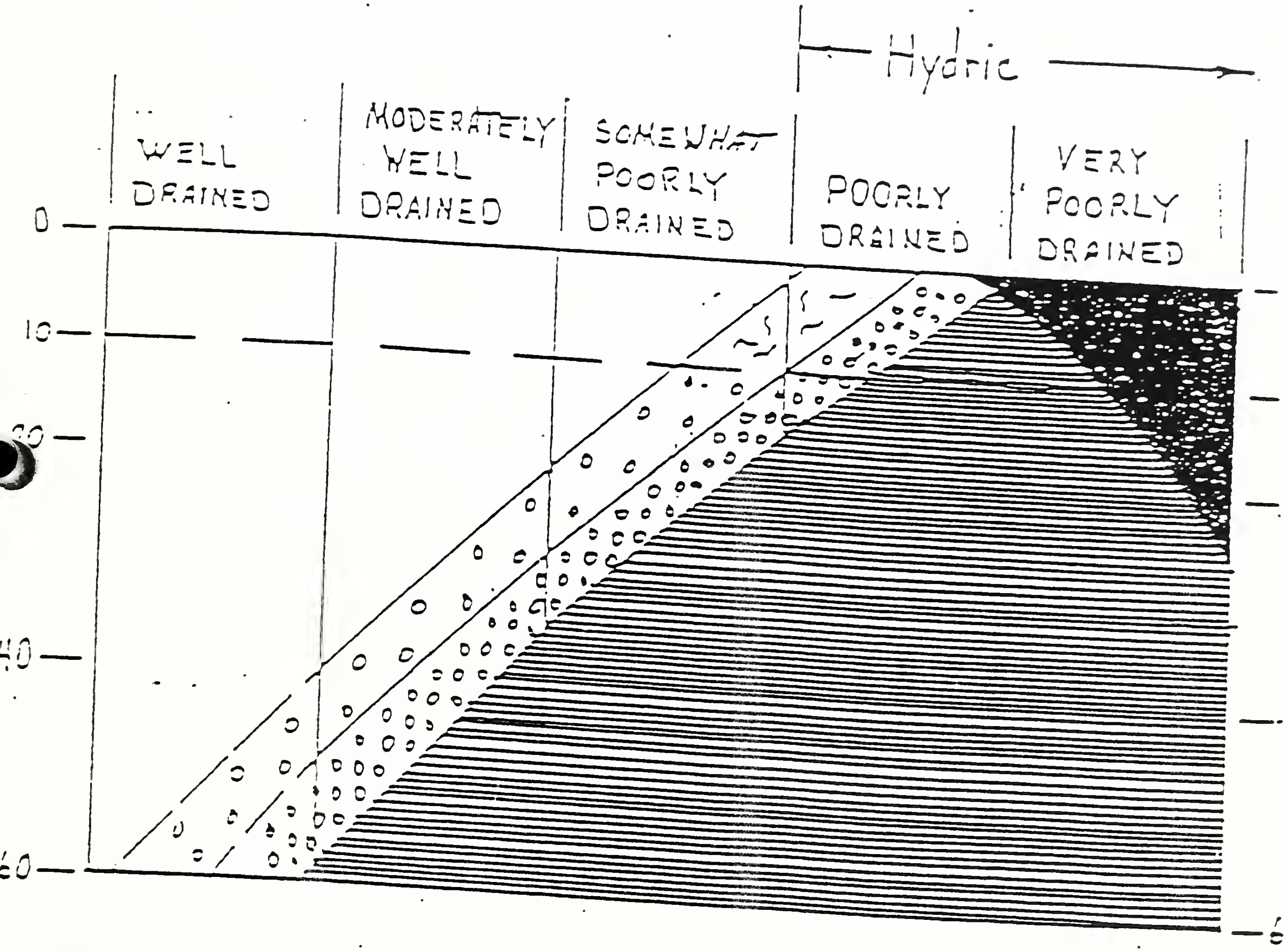
FINS SI

LATERAL

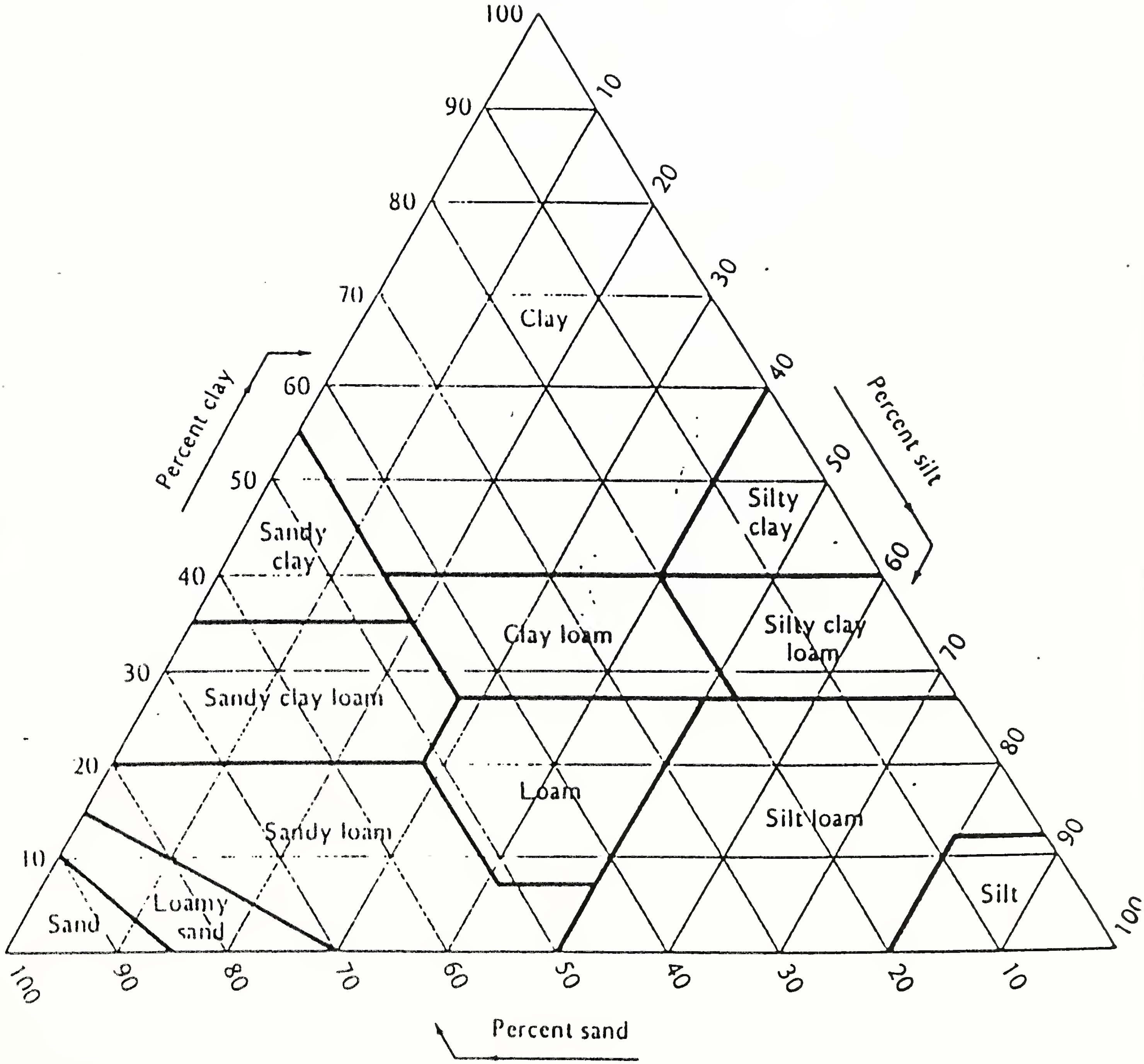
SCALES


Oi Organic, slightly decomposed
Oe Organic, moderately decomposed
Oa Organic, highly decomposed
A Mineral, mixed with humus, dark colored
E Horizon of maximum eluviation of silicate clays, Fe, Al oxides, etc.
AB or EB Transition to B, more like A or E than B
BA or BE Transition to A or E, more like B than A or E
B Most clearly expressed portion of B horizon
BC Transition to C, more like B than C
C Zone of least weathering, accumulation of Ca, Mg carbonates, cementation, sometimes high bulk density
R
Solum
Bedrock

Natural Soil Drainage Classes
For Agricultural Purposes



- High Organic Matter, O-horizon
- Gleyed >90% Gray
- Mottled - Predominantly Gray ≥ 60%
- Mottled - (Red and Gray)



Percent clay
Percent silt
Percent sand
Clay
Sandy clay
Silty clay
Clay loam
Silty clay loam
Sandy clay loam
Loam
Silt loam
Sandy loam
Loamy sand
Sand
Silt

U.S. Department of Agriculture classification system

General terms		
Common names	Texture	Basic soil textural class names
Sandy soils	Coarse	Sands Loamy sands
Loamy soils	Moderately coarse	Sandy loam Fine sandy loam[a]
	Medium	Very fine sandy loam[a] Loam Silt loam Silt
	Moderately fine	Sandy clay loam Silty clay loam Clay loam
Clayey soils	Fine	Sandy clay Silty Clay Clay

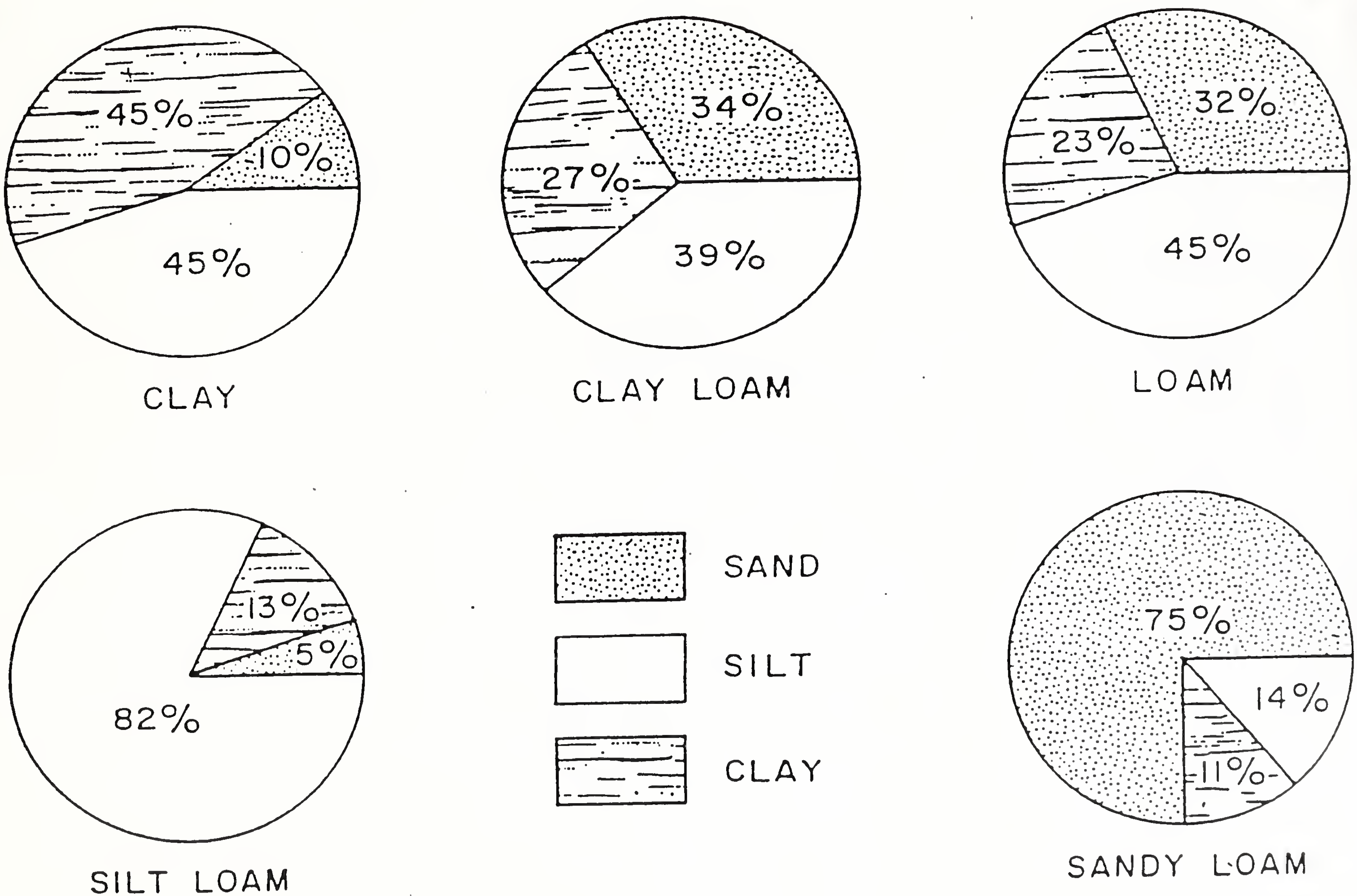


Figure 10. Percent of sand, silt and clay in soils of various textures.

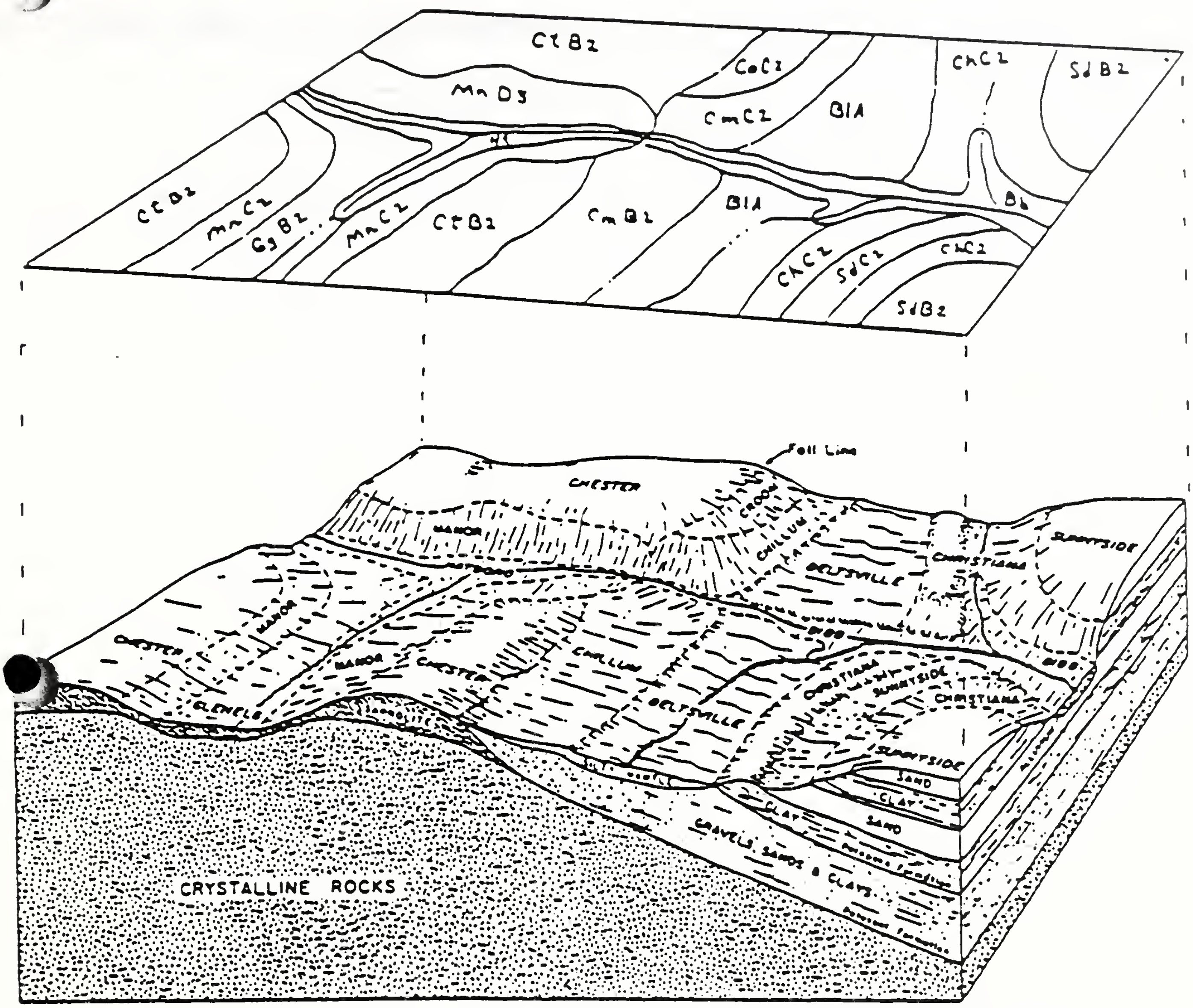


FIG. 1—*Block diagram of contact* (fall line) *between the Piedmont and Mid-Atlantic Coastal Plain showing relationship of parent materials and topography to soil map units and soil map.*

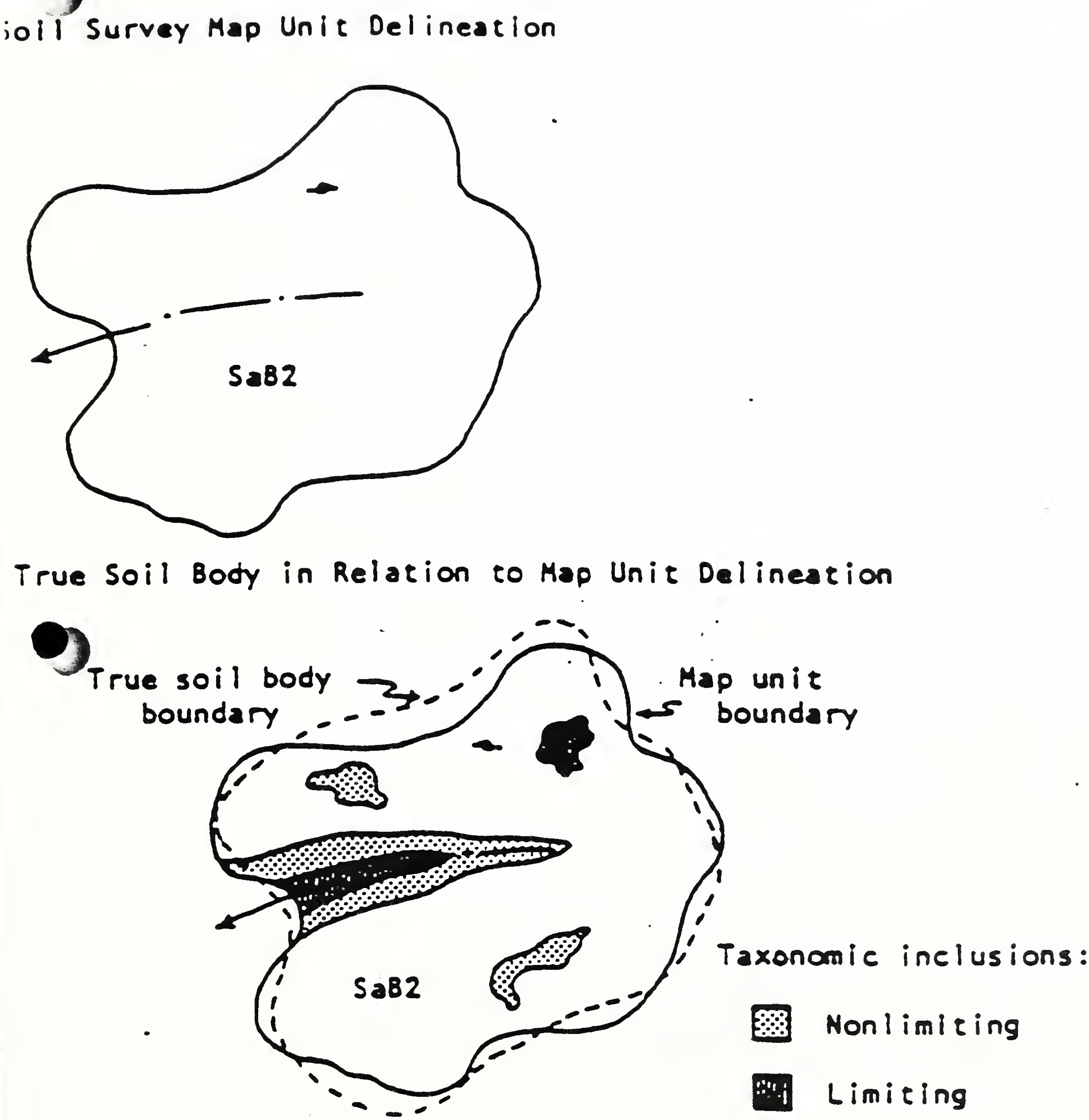
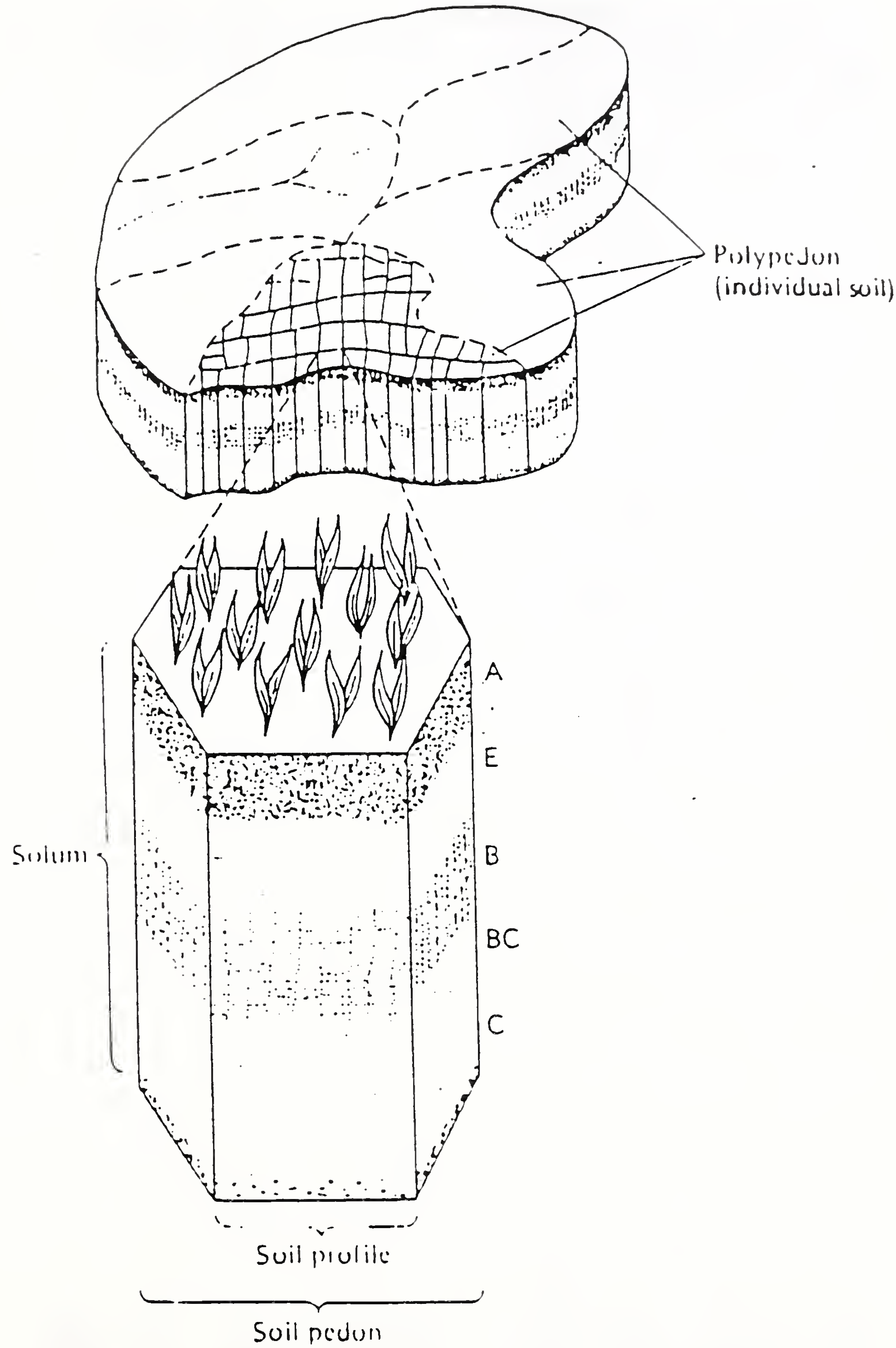


FIG. 5—*Soil survey map unit delineation of soil body as perceived by soil surveyor compared to actual soil body showing taxonomic inclusions. Inclusions may be similar to the taxon for which the map unit is named and, therefore, be nonlimiting for interpretive purposes; or they may be dissimilar enough to restrict the land uses suitable for the dominant taxon.*


Polypedon
(individual soil)
A
E
B
BC
C
Solum
Soil profile
Soil pedon

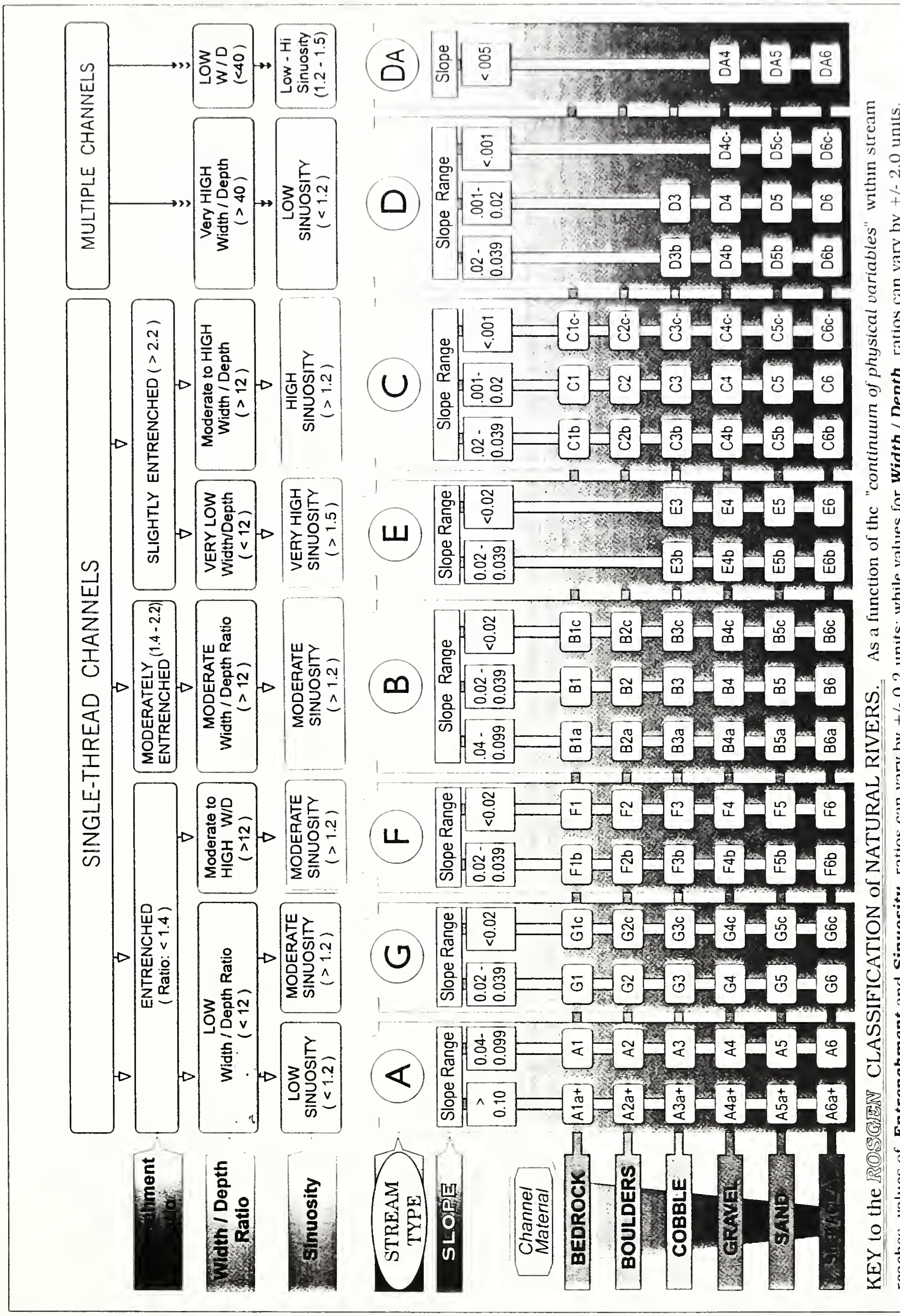


FIGURE 5-3. Classification key for natural rivers.

Historical Background Behind the Sleepy Hallow Stream Restoration.

I first want to welcome everyone to the Beltsville Agricultural Research Center (BARC). As you may be aware the Center is the largest Agricultural Research Center in the world. Not in size, but in the number of scientists and facilities. With this distinction comes the huge responsibility of taking care of the land. As a member of the Farm Operations Branch it is our task to watch over the fields, streams and forests of the Center. It's a charge that we take very seriously. The project that you will be studying over the next two days is an example of our commitment to this charge. It is also an example of how government and state agencies can cooperate, pool their resources and come up with solutions.

Our philosophy on agriculture is changing. We have been charged to find ways to make the practices of agriculture more environmentally friendly. The sleepy hallow stream restoration is an example of this new approach. This bioengineering concept checks erosion, filters nutrient runoff, cools the waters, moderates stream flow and offers quality wildlife habitat. These are some of the practices that we are trying to promote in USDA's sustainable agriculture initiative.

Five years ago a new housing development was built off of Sellman Road. This development dramatically changed the drainage pattern from the area onto our property. Suddenly what had been an intermittent waterway, became a continuously flowing stream with significant storm surges. We lost a small bridge, the stream bed became unstable and began to undercut our research plots. We contacted the Army Corp of Engineers, NRCS and others for solutions. NRCS came forward with the idea of the bioengineered restoration. A small task force was formed that included the people that will be speaking today. Construction began in the fall of 1996. Because this was a new concept the construction phase progressed slowly. However, it was not long before the personnel working on the project could see tangible results. Today, you will see a very active, healthy stream, teaming with all types of flora and fauna. Its still developing and we are continually learning from it.

I hope that you will take back with you an appreciation for what the people who worked on this project were able to do. If you are able to use the technology that was developed here then I consider this project a success. I hope you enjoy your day at BARC and find it rewarding.

VORTEX ROCK WEIR INSTALLATION

NOTE: Vortex Rock weirs should be installed at the top and bottom of each meander bend. Boulders should be 16" to 24" diameter, minimum. The top of the footer rocks sets the design elevation for the stream invert.

1. Excavate the trench for the Vortex Rock Weir, such that the top of the footer rocks are at the design elevation of the stream invert. Place the footer rocks in the trench with as little space as possible between rocks.

2. Place the upper weir rocks slightly in front of the footers, so that at least 2/3 of the rock diameter will be buried below the elevation of the stream invert. The spacing between upper weir rocks should be as close to 1/2 the diameter (D) of the rocks. The arc of the weir should be such that there is a distance of approximately 2.5D between the leading edges of the upstream-most and downstream-most rocks. The top of the upstream-most rock should be at 15% - 20% of the bankfull elevation, and the top of the outermost rocks on each side should be at the design bankfull elevation. The tops of intermediate rocks should be on an even slope between the leading and edge rocks.

3. Backfill around upper weir rocks with natural bed material. Excavate scour pools a distance of 3-4D upstream and downstream of the weir, leaving at least 2/3 of the footer rocks below grade in the downstream scour zone.

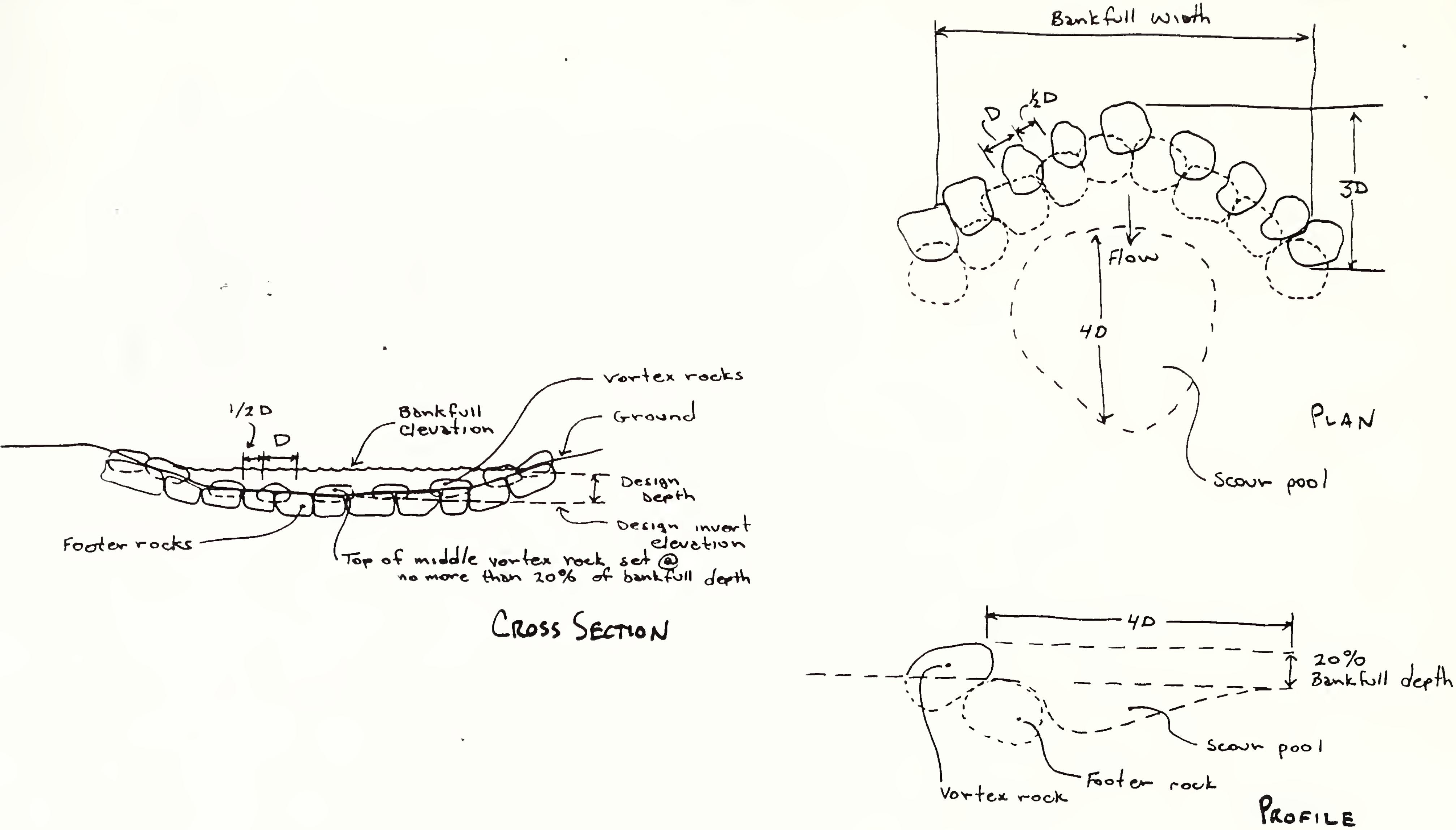


Figure 5. Vortex Rock Weir.
Typical (NOT TO SCALE).

MD Bellsville ARS

APB/TMD/BN/RG 3/27/95

Stream Restoration 1

Lower Cross Section

W/D Ratio = 18.3
Entrenchment Ratio = 1.4
Slope = .02 (Water Surface)
Sinuosity = 106/76 = 1.4
n = .039
Class B4 / G4

Middle Cross Section

W/D Ratio = 11.8
Entrenchment Ratio = 1.3
Slope = .013 (water Surface)
Sinuosity = 1.03
n = .04
Class G5 / B5

Upper Cross Section

W/D Ratio = 10.8
Entrenchment Ratio = 2.5
Slope = .014 (Water Surface)
Sinuosity = 1.5
n = .032
Class E5

D.A. = 180 ac = 0.28 mi^2

Q_{BF} Lower

D_{50} = Gravel $\Rightarrow$ n = .039 from chart

$= \frac{1.49}{n} r^{2/3} S^{1/2} A$

$r = \frac{a}{p} = \frac{6.6}{11} = .6$

A = mean depth x width

$= \left(\frac{1.49}{.039}\right)(.6)^{2/3}(.02)^{1/2}(6.6)$

$Q_{BF} = 25$ cfs

width

r = area/BF width

Q_{BF} Middle

$Q_{BF} = \frac{1.49}{n} r^{2/3} S^{1/2} A$

$= \frac{1.49}{.04} (0.8)^{2/3} (.013)^{1/2} (7.78\ ft^2)$

Q_{BF} = 29 cfs

Q_{BF} Upper

$Q_{BF} = \frac{1.49}{.032} (.56)^{2/3} (.014)^{1/2} (7.89)$

n = .032
S = .014
a = 7.89
r = .56

Q_{BF} = 20 cfs (n = .047) Veg.
Q_{BF} = 30 cfs (n = .032) No Veg.

DESIGN TYPE B CHANNEL FROM 0+00 to 3+00

Parameters -

Entrenchment Ratio 1.4 - 2.2
Width/Depth Ratio > 12
Sinuosity > 1.2
Slope Range 0.02 - 0.039
$r_m = 2.9 \times BFW$
$L_m = 10-14 \times BFW$
$BFW = \sqrt{W/D \cdot A}$

Determine A_{BF} for B type (Fig. 11, C23)

$A_{BF} = 10\ ft^2$ for 30 cfs

$BFW = \sqrt{A \cdot W/D}$ choose W/D = 12 from above

$\therefore BFW = \sqrt{10 \times 12} = \underline{11.0\ ft}$

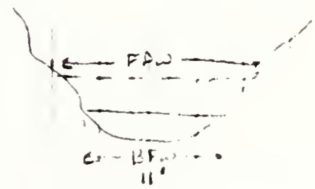
$W/D = 12 = \frac{11.0}{D_{mean}} \Rightarrow D_{mean} = \underline{0.92\ ft}$ $D_{MAX} = 1.5\ ft$ (from cross section for $A = 10\ ft^2$)

Meander Width Ratio (MW Ratio) = $\frac{\text{Beltwidth}}{\text{BFW}}$

Assume: MW Ratio = 2 (Catina C 43 - Fig. 2) low end limited space minimize excav.

$2 = \frac{\text{Beltwidth}}{11.0} \Rightarrow$ Beltwidth = $\underline{22\ ft}$ ok

Determine Flood Prone Width = Entr. Ratio × BFW



Current FPW = 15.5 ft (6 type)

Low Entr. Ratio - 1.4

FPW = 1.4 (11.0) = 15.4 = current - try larger

Try Entr. Ratio = 2.0

FPW = 2.0 (11.0) = 22 ft ... ok

can increase to 2.4 × 11.0 = 26.5 ft FPW No, too much excavation

Use Entr. Ratio = 2.0

Mean Radius of Curvature = r_m = 2.9 × BFW

= 2.9 × 11 = 32 ft.

Determine Meander Length = L_m = 10 - 14 × BFW

Plotting r_m = 32

$L_m \cong \frac{98 \text{ ft}}{\text{BFW}} = \frac{98}{11} = 9$ < 10 ok?

Sinuosity = $\frac{105}{98}$ = 1.1 ok

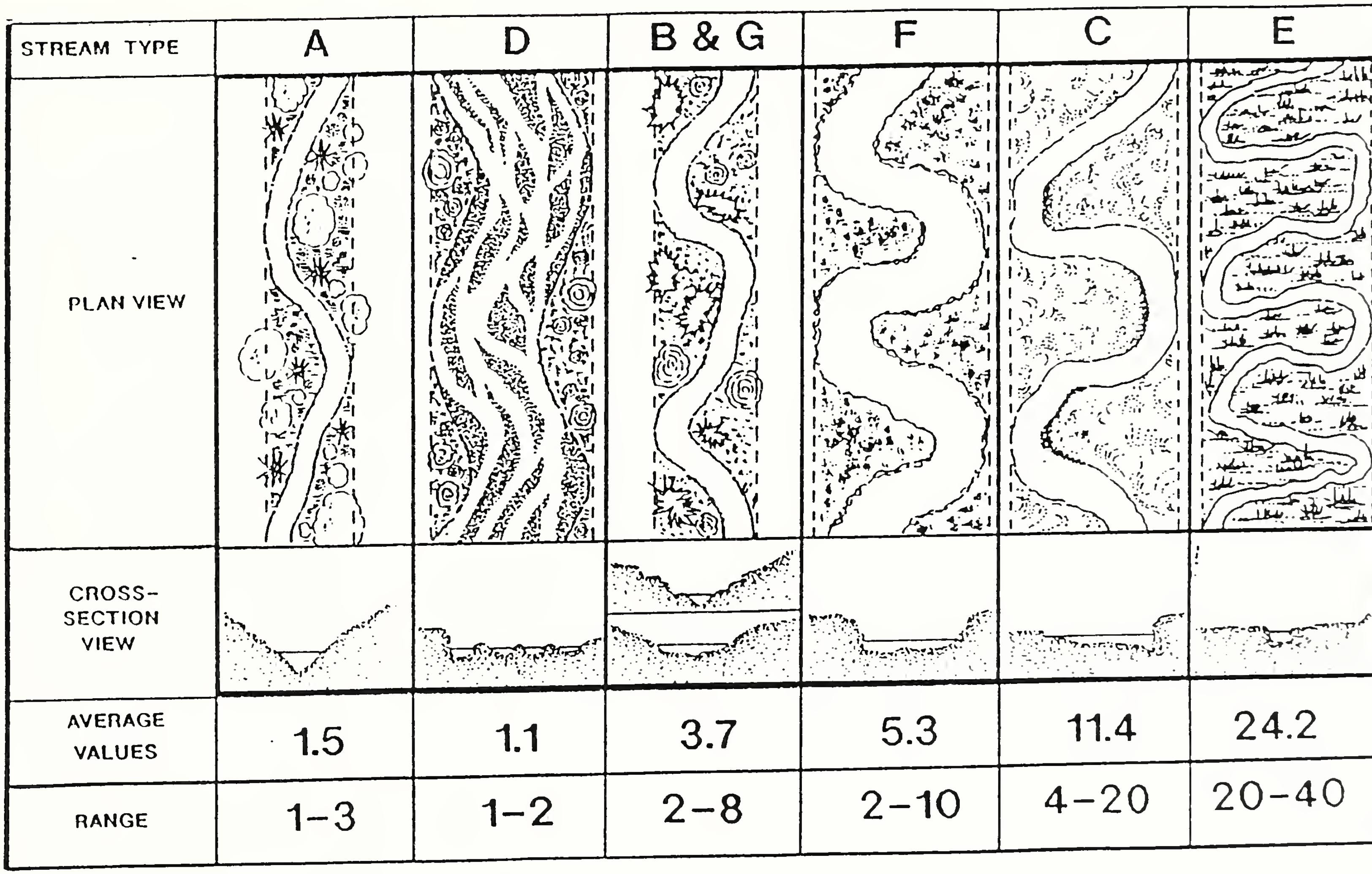
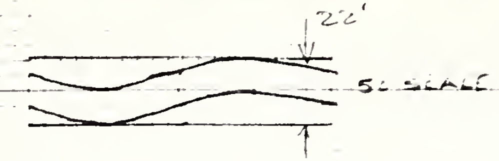
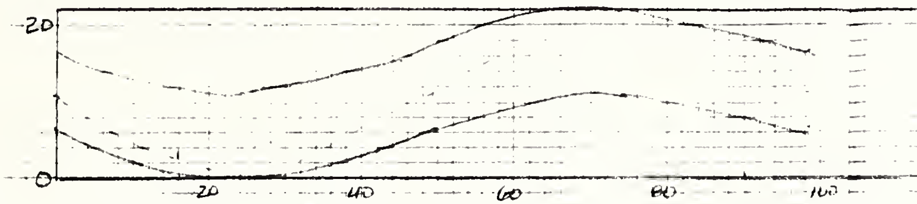
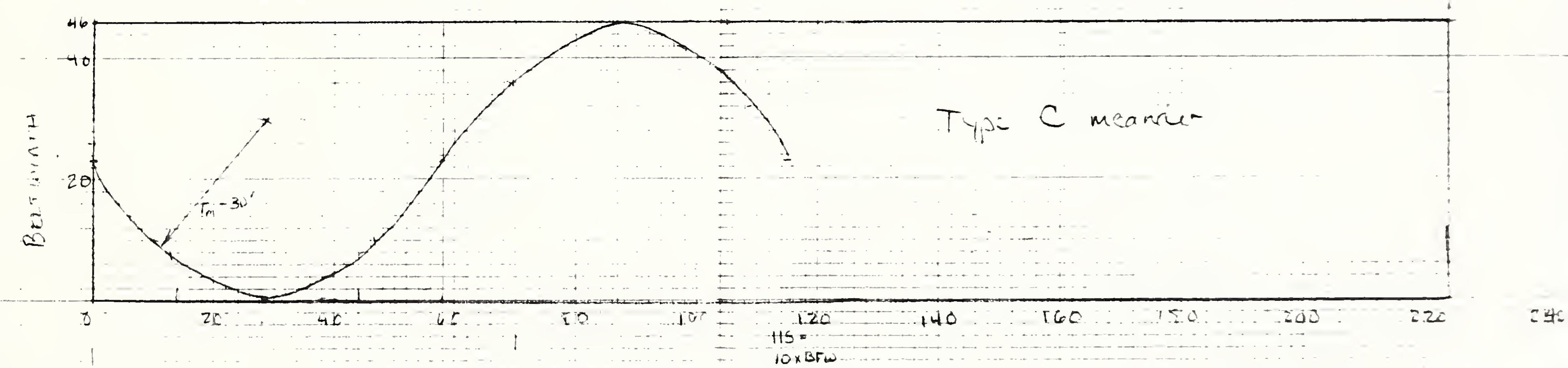


Figure 2. Meander width ratio (belt width/bankfull width) by stream type categories.





TYPE "B" CHANNEL
TYPICAL MEANDER



Type C meander

1" = 20' V/H

STA 3+00 to 12+85

ARS STREAM RESTORATION

MEANDER LENGTH
RADIUS OF CURVATURE

USDA
NATURAL RESOURCES
CONSERVATION SERVICE
MARYLAND
CONSERVATION PRACTICE
STANDARD
RIPARIAN FOREST BUFFER

CODE 391
(Reported in Acres)

DEFINITION

An area of trees and/or shrubs located adjacent to and up-gradient from water bodies.

PURPOSES

1) Reduce excess amounts of sediment, organic material, nutrients, pesticides and other pollutants in surface runoff and reduce excess nutrients and other chemicals in shallow ground water flow.

2) Create shade to moderate water temperatures to improve habitat for fish and other aquatic organisms.

3) Provide a source of detritus and large woody debris for fish and other aquatic organisms.

4) To provide riparian habitat and corridors for wildlife.

CONDITIONS WHERE PRACTICE APPLIES

On stable areas adjacent to permanent or intermittent streams, lakes, ponds, wetlands and areas with ground water recharge. (For areas with unstable banks refer to Streambank Stabilization, practice 580.)

CRITERIA

Criteria Applicable To All Purposes

The location, layout, width, length and woody plant density of the riparian forest buffer will be selected to accomplish the intended purpose and function. The buffer will consist of a zone (identified as zone 1) that begins top of bank, and extends a minimum distance of 15 feet, measured horizontally on a line perpendicular to the water course or water body.

NOTE: The ability to sustain a healthy forest condition, and reduction of sediment, organic material, nutrients and pesticide will be limited if only Zone 1 is established. A minimum buffer width of 35 feet is required in the Chesapeake Bay drainage area.

Dominant vegetation will consist of existing or planted trees and shrubs suited to the site and the intended purpose. Selection of locally native species will be a priority when feasible. Plantings will consist of two or more species in an attempt to achieve greater diversity. Individual plants selected will be suited to the seasonal variation of soil moisture status of individual planting sites. Plant types and species shall be selected based on their compatibility in growth rates and shade tolerance. Select species from the Plant Lists located in Specifications.

Occasional removal of some tree and shrub products such as high value trees is permitted provided the intended purpose is not compromised by the loss of vegetation or harvesting disturbance. *(An approved sediment and erosion control plan is required when harvesting disturbs over 5000 sq. ft., and in the Chesapeake Bay Critical Area a Timber Harvest Plan is required.)*

An adequate upstream or adjacent seed source must be present when using natural regeneration to establish a buffer. Planting is preferred over natural regeneration due to control of plant species present and reduced time for woody plants to reach maturity.

Conservation practice standards are reviewed periodically, and updated if needed. To obtain the current version of this standard, contact the Natural Resources Conservation Service.

Necessary site preparation and planting for establishing new buffers shall be done at a time and manner to insure survival and growth of selected species. Refer to Specifications for care, handling, and planting requirements for woody planting stock.

Only viable, high quality, and adapted planting stock will be used. The method of planting for new buffers shall include hand or machine planting techniques, suited to achieving proper depths and placement for intended purpose and function of the buffer.

Site preparation shall be sufficient for establishment and growth of selected species and be done in a manner that does not compromise the intended purpose. Refer to Specifications for woody planting stock quality requirements and detailed site preparation procedures. Supplemental moisture will be applied if and when necessary to assure early survival and establishment of selected species.

Livestock shall be controlled or excluded as necessary to achieve and maintain the intended purpose. Water course crossings and livestock watering shall be located and sized to minimize impact to buffer vegetation and function. (See Fencing, 382 and Stream Crossing, 232 Standards.)

Harmful pests present on the site will be controlled or eliminated as necessary to achieve and maintain the intended purpose.

Additional Criteria Purpose 1

To reduce excess amounts of sediment, organic material, nutrients, pesticides and other pollutants in surface runoff and reduce excess nutrients and other chemicals in shallow ground water flow.

An additional strip or area of land, (Zone 2), will begin at the edge and up-gradient of zone 1 and extend a minimum distance of 20 feet, measured horizontally on a line perpendicular to the water course or water body. The minimum combined width of zones 1 and 2 will be 100 feet OR 30 percent of the geomorphic flood plain whichever is less, but not less than 35 feet. A Geomorphic floodplain is defined as the area adjacent to a river or stream that is built of alluvial sediments that are associated with the present depositional activity. *(Note: The geomorphic floodplain does not include older land forms, such as terraces, that were formed by similar process but under different hydrologic conditions. These upland terrace positions no longer flood and subsequently do not receive additional alluvial sediments.)* Figure 1 illustrates examples of zone 1 and 2 widths for water courses and water bodies.

Zone 2 may need to be adjusted to include important resource features such as wetlands, steep slopes, or critical habitats.

In this zone the removal of tree and shrub products such as timber, nuts and fruit is permitted on regular basis provided the intended purpose is not compromised by loss of vegetation or harvesting disturbance.

Additional Criteria Purpose 2

To create shade to moderate water temperatures to improve habitat for fish and other aquatic organisms.

A buffer for controlling warm-season water temperatures shall consist of at least zone 1 for water course reaches or water bodies less than or equal to 30 feet in width or water bodies greater than 30 feet wide but less than 1 acre. (NOTE: Buffers for wider water courses or larger water bodies may be valuable but will have only site-specific effects.)

Buffers shall be established or maintained on south and west sides of water courses and bodies insofar as practical. The buffer canopy shall be established to achieve at least 50 percent crown cover with average canopy heights equal to or greater than the width of the water course or 30 feet for water bodies. (See figure 2.)

Buffer species shall include those species listed in the Plant List, Table 1, Specifications, with sufficient height potential. Place drooping or wide-crowned trees and shrubs nearest the water course or body. Shoreline or channel relief (e.g., deeply incised channels) and topographic shading will be taken into account in selecting species.

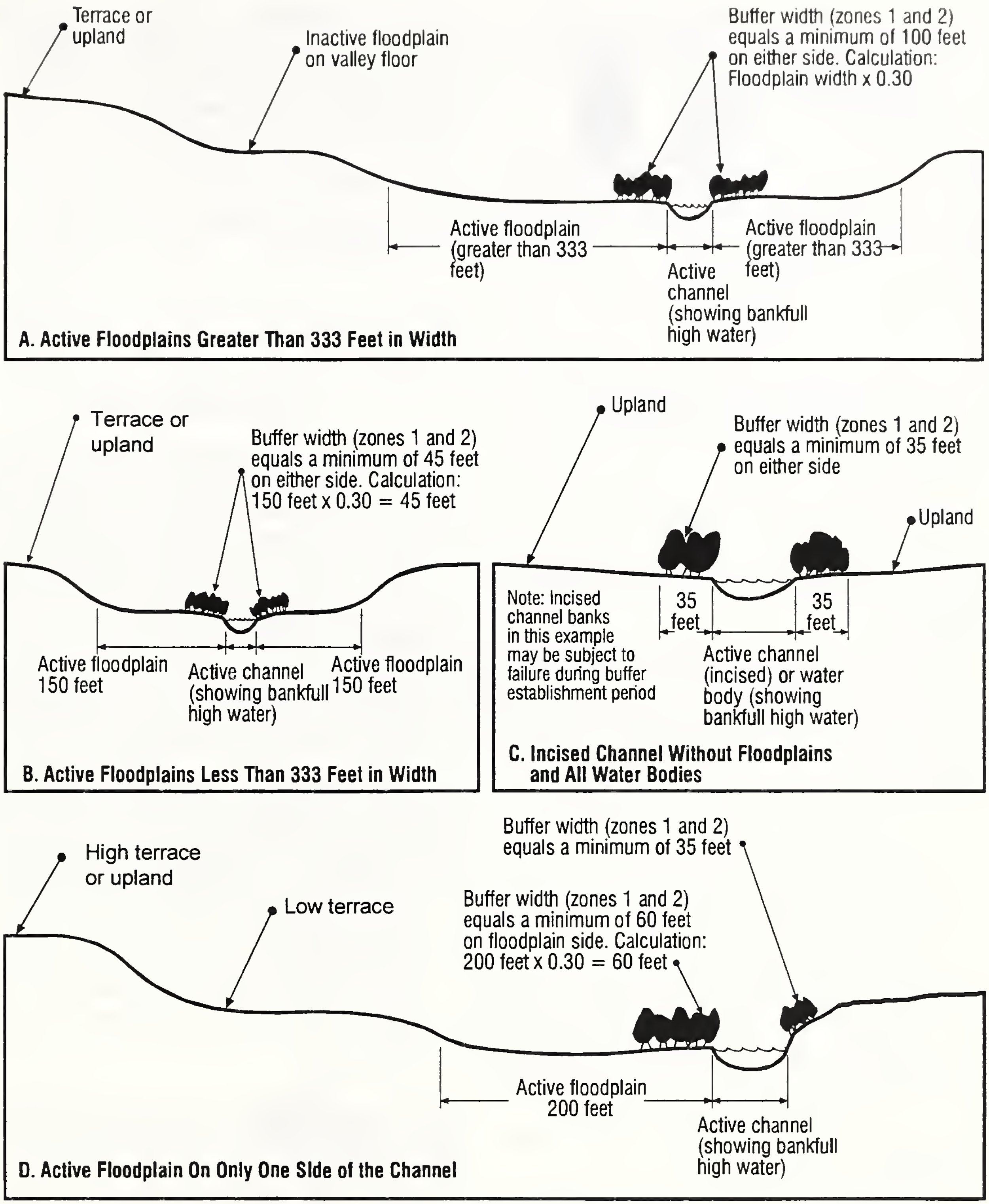


Figure 1. Examples of riparian forest buffer widths for water courses and water bodies.

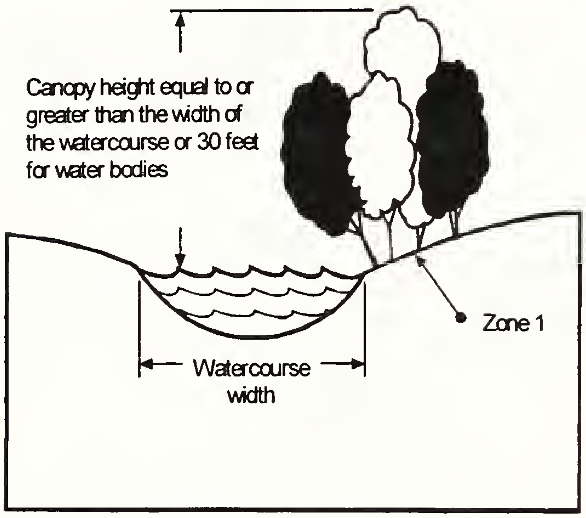


Figure 2. Canopy height for water temperature control.

Additional Criteria Purpose 3

To provide a source of detritus and large woody debris for fish and other aquatic organisms.

Within zone 1 as a minimum, establish, favor or manage species capable of producing stems and limbs of sufficient size to provide an eventual source of large woody debris for instream habitat for fish and other aquatic organisms.

Additional Criteria Purpose 4

To provide wildlife habitat.

Select trees and shrubs that provide food cover and shelter for the targeted wildlife species. See Plant list in the Specifications section and refer to Wildlife/Wetland Habitat Management Standards 644, 645 for more information.

Buffer Width Guide for Selected Wildlife Species.

Widths below include the sum of buffer widths on one or both sides of water courses or water bodies and may extend beyond riparian boundaries (in such cases refer to Tree/Shrub Establishment, 612 for design of upland forests).

Species:	Desired Width in Feet
Bald eagle nesting, cavity nesting ducks, heron rookery	600
Neotropical migrants	300
Beaver, dabbling ducks, mink, salmonids	300
Deer	200
Frog, salamander	100

CONSIDERATIONS

The severity of bank erosion and its influence on existing or potential riparian trees and shrubs should be assessed. Watershed-level treatment or bank stability activities may be needed before establishing a riparian forest buffer. (Refer to Streambank Protection Standard, 580 and to Chapter 18 of the Engineering Field Handbook.)

Complex ownership patterns of riparian areas may require group planning for proper buffer design, function and management.

Where ephemeral, concentrated flow or sheet and rill erosion and sedimentation is a concern in the area up-gradient of zone 2, consider the application of a vegetated strip consisting of grasses and forbs, (Zone 3). Grasses and forbs from plant list #2 established at the up-gradient edge of zone 2 will accelerate deposition of sediment. (See figure 3.) When concentrated flow or excessive sheet and rill erosion and sedimentation cannot be controlled vegetatively, consider structural or mechanical treatments.

Joining existing and new buffers increases the continuity of cover and will further moderate water temperatures, improve habitat and enhance water quality functions. A mix of species with growth forms that are tall and wide-crowned or drooping will increase moderation effects. For water courses, buffers established on both sides will enhance multiple values.

Favor tree and shrub species that are native and have multiple values such as those suited for timber, biomass, nuts, fruit, browse, nesting, aesthetics and tolerance to locally used herbicides. Consider species that resprout when establishing new rows nearest to water courses or bodies. For detritus and large woody debris, use species that will meet the specific requirements of fish and other aquatic organisms for food, habitat, migration and spawning.

Use recommendations from regional or other large-scale evaluations and plans when designing, locating and connecting buffers for indicator and/or target species of wildlife, fish and other aquatic organisms.

Avoid tree and shrub species which may be alternate hosts to undesirable pests or that may be considered noxious or undesirable. Species diversity should be considered to avoid loss of function due to species-specific pests.

The location, layout and density of the buffer should complement natural features. Avoid layouts and locations that would concentrate flood flows or return flows. Low, flexible-stemmed shrubs will minimize obstruction of local flood flows.

Consider the positive and negative impacts beaver, muskrat, deer, rabbits and other local species may have on the successful management of the riparian and stream system.

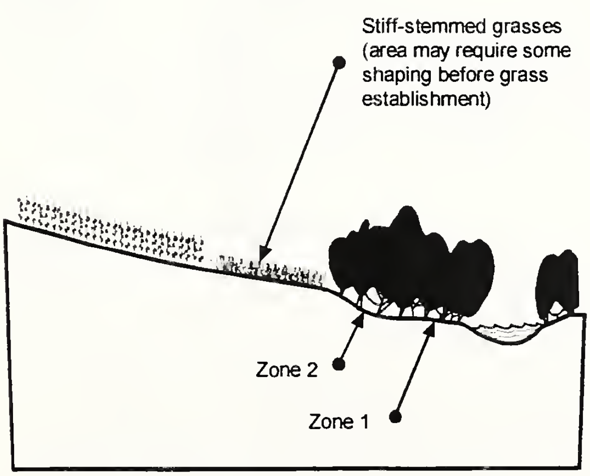


Figure 3. Sediment-trapping above zone 2.

Temporary and local population control methods of these kinds of local species should be used cautiously and within state and local regulations.

Consider the type of human use (rural, suburban, urban) and the aesthetic, social and safety aspects of the area to determine the vegetation selection, arrangement and management. For example, avoiding tall shrubs that block views and pruning low tree branches near recreation trails allows for ease of patrolling.

Species selection criteria to improve aesthetics include seasonal foliage color, showy flowers and fruit, foliage texture, form and branching habit. The layout and design should be appropriate for the setting as determined by adjacent land uses.

SPECIFICATIONS

Specifications for this practice shall be prepared for each site. Requirements for operation and maintenance of the practice shall be incorporated into site specifications.

Procedures, technical details and other information listed below provide additional guidance for carrying out selected components of the named practice. This material is referenced from the conservation practice standard for the named practice and supplements the requirements and considerations listed therein.

Planting Densities

Initial plant-to-plant densities for trees and shrubs will depend on their potential height at 20 years of age. Be sure to consider management when planting. If mowing will be method of weed control, row widths must be wide enough to allow access. Heights may be estimated based on: 1) performance of the individual species (or comparable species) in nearby areas on similar sites, or 2) predetermined and documented heights using Conservation Tree/Shrub Suitability Groups, Section II of the Field Office Technical Guide.

Planting density specifications are:

Plant Types/Heights:	Plant-to-Plant Spacing in feet:
• Shrubs less than 10 feet in height	6
• Shrubs and trees from 10 to 25 feet in height (includes columnar trees)	6 to 8
• Trees greater than 25 feet in height	8 to 12

Plant List

Table 1 lists woody plant species (trees and shrubs) commonly associated with and suited to riparian areas. Key attributes are listed for each plant to assist with the design process for establishing new buffers.

Care, Handling, Size And Planting Requirements For Woody Planting Stock

During all stages of handling and storage, keep stock tops dry and free of mold and roots moist and cool. Destroy stock that has been allowed to dry, to heat up in storage (e.g., within a bale, delivery carton or container), or that has developed mold or other pests.

Seedlings shall no be less than 1/4" in caliper at 1" above the root collar. Rooted planting stock must not exceed a 2:1 shoot-to-root ratio. (See figure 4.) Container stock shall normally not exceed a 1-gallon size.

Roots of bareroot stock shall be kept moist during planting operations by placing in a water-soil (mud) slurry, peat moss, superabsorbent (e.g., polyacrylamide) slurry or other equivalent material. Rooting medium of container or potted stock shall be kept moist at all times by periodic watering. Stock shall not be planted when the soil frozen or dry. Rooted stock will be planted in a vertical position with the root collars approximately 1/2-inch below the soil surface. Insert cuttings to the depth

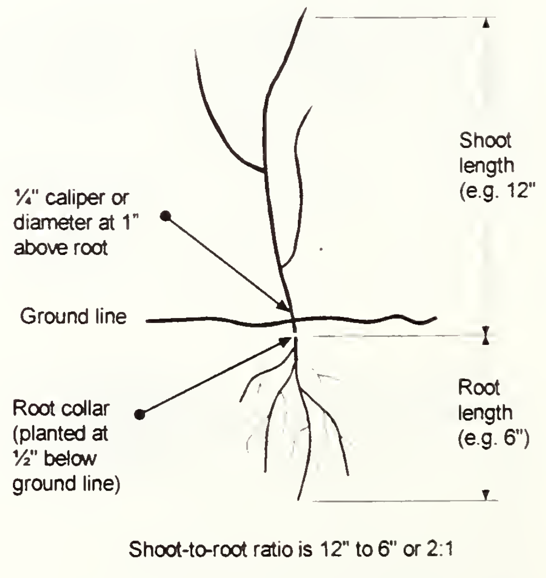


Figure 5. Plant or stock size requirements.

required to reach adequate soil moisture with at least 2-3 buds above ground. The planting trench or hole must be deep and wide enough to permit roots to spread out and down without J-rooting or L-rooting. After planting of rooted stock, pack soil around each plant firmly to eliminate air pockets. (See figure 5.)

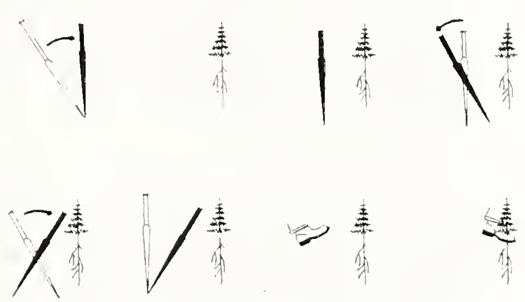


Figure 5. Proper plant and root placement of rooted stock using a planting bar.

Recommended Planting Dates

MLRA 149A, 153C and 153D - March 1 to May 11; planting may be done on sandy soils, when soil is not frozen, during the fall and winter months. (After November 1)

MLRA 148 - March 1 to May 1

MLRA 147 and 130 - March 15 to May 1

MLRA 127 - April 1 to May 15

Containerized stock can be planted at any time the ground is not frozen provided a water source is available.

Preparation Of Planting Sites

Planting sites shall be properly prepared based on the soil type and vegetative conditions listed below. For sites to be tilled, leave a 3-foot undisturbed strip at the edge of the bank or shoreline. Competitive weeds, particularly Canada Thistle and Multiflora Rose should be controlled prior to planting. Avoid sites that have had recent application of pesticides harmful to woody species to be planted. If pesticides are used, apply only when needed and handle and dispose of properly and within federal, state and local regulations. Follow label directions and heed all precautions listed on the container.

Fabric mulch may be used for weed control and moisture conservation for new plantings, particularly those with pronounced growing season moisture deficits or invasive, weedy species. Refer to Mulching, 484, for installation procedures.

Based on site conditions and predominant soil texture of the fine earth fraction, procedures include:

Tillable sites with loamy/clayey soils:

- Sod and alfalfa sites

  Summer fallow 1 year to kill the sod or alfalfa. Till (moldboard plow, disk plow, rototiller or similar equipment) in the spring before planting the stock. A fall-sown crop of oats may be used where needed to control erosion.

  Sod may be killed by non-selective herbicides the year previous to planting stock. Plant stock in the residue. On heavy soils, tillage is usually necessary to achieve a satisfactory planting when a tree planting machine is used.

- Small grain or row crop sites

  If the site is in row crop, till (moldboard plow, disk plow, rototiller or similar equipment) in the fall or in the spring prior to planting the trees or shrubs. If the site has a plow or hard pan in subsoil, perform a deep disking or ripping operation in the fall. A fall-sown crop of oats may be used where needed to control erosion.

  If the site is in small grain stubble, the stock may be planted in the spring without further preparation. If fabric mulch is to be installed, till in the spring before planting.

  Tillage on steep slopes must be on the contour or cross-slope. A cover crop between the rows may be necessary to

control erosion and sediment deposition on planted stock.

Tillable sites with sandy soils:

- Sod and alfalfa sites

Till (moldboard plow, disk plow, rototiller or similar equipment) and plant to a spring cover crop (corn, grain, sorghum, etc.) the year prior to planting. Leave a stubble cover in which to plant. A light disking may be needed before planting if fabric mulch is used.

Sod may be killed by nonselective herbicides the year prior to planting. Plant trees or shrubs in the residue.

When hand planting, scalp or strip an area at least 3 feet in diameter and two-to-four inches deep. (place plants in the center of the scalped area.)

Rototill a 3-foot wide strip. (Place plants in the center of the tilled area.) Where a drip watering system will not be used, rototill the strip the year prior to planting.

- Small grain or row crop sites

If the site is in small grain, corn, or similar clean tilled crop, and it is reasonably free of weeds, plant stock in the stubble without prior preparation. It may be necessary to till a narrow strip with a disk or other implement to kill weeds or volunteer grain, or to prevent stalks and other residue from clogging the tree planter. If fabric mulch is used, disking may also be needed. A cover crop or stubble may be needed between the rows to protect the planting from water or wind erosion.

Non-tillable sites and/or erosive sites (including sites with undesirable brushy or herbaceous species):

On sites where it is not practical or possible to operate equipment (steepness, rockiness, etc.), where tillage of the site will cause excessive erosion, or where tillage of the site is impractical, the methods listed below may be used. Sites with undesirable brush will need initial treatments that physically removes and kills the brush species to facilitate planting of desired stock and prevent re-encroachment of the brush. Suitable methods include hand-cutting and removal, brush hogging, brush-blading, or other equivalent procedure with repeated treatment or use of herbicides to control re-sprouting.

Machine or hand scalp an area at least 36 inches in diameter with subsequent plant placement in the center of the scalped area.

Rototill a strip at least 36 inches wide the year prior to tree planting with subsequent plant placement in the center of the tilled strip.

Kill the vegetation in a 36-inch diameter or larger area or in a 36-inch or wider strip with a non-selective herbicide the year prior to planting and plant in the center or along the center-line of the treated area.

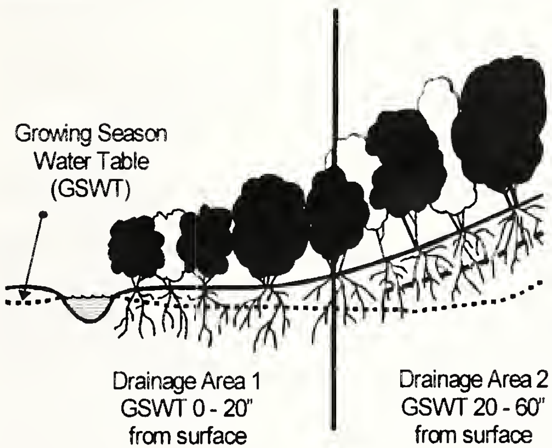


Figure 6. Drainage Class Suitability

This is a simplified drawing depicting the major drainage areas found in a riparian area and is intended to facilitate the plant selection process. Area 1 is made up of poorly drained to somewhat poorly drained soils with the growing season water table (GSWT) fluctuating from 0 to 20" from the soil surface in most years. This area has the greatest potential for inundation.

Area 2 is made up of moderately well to well-drained soils with the GSWT fluctuating from 20" to 60" from the soil surface in most years. This area is prone to moisture stress during the summer months.

The plants in the following tables have been separated according to their suitability for the conditions in Area 1 or 2. Plants with both areas listed are tolerated of a wide range of conditions.

TABLE 1 - TREES

Plant Names	Drainage Area Suitability	Tolerance to Flooding	Shade Value	Height 20 Years	Native Species	Wildlife Value	Notes
ATLANTIC WHITE CEDAR Chamaecyparis thyoides	1	M	M	30'	Y	Low: seed and browsing	cannot compete with hardwoods, best planted in stands
BALD CYPRESS Taxodium distichum	1	H	M	40'	Y	Low: seeds, food for ducks and marsh birds	recommended for lower Eastern Shore only
BLACK ALDER Alnus glutinosa	1	H	M	40'	N	Medium: food for beaver and ruffed goose	seeds freely along banks, nitrogen fixing
BLACK WALNUT Juglans nigra	1	M	H	60'	Y	Medium: twigs and nuts, food for some wildlife	very important lumber tree
BLACK WILLOW Salix nigra	1	H	H	75'	Y	Medium: nesting, food for grouse, beaver, and deer	important for stream stabilization, fast growth rate

TABLE 1 - TREES

Plant Names	Drainage Area Suitability	Tolerance to Flooding	Shade Value	Height 20 Years	Native Species	Wildlife Value	Notes
BOX ELDER Acer negundo	1	H	M	30'	Y	Low: seeds, food for some wildlife	fast growth rate
RIVER BIRCH Betula nigra	1	H	M	40'	Y	Medium: food for ducks, songbirds, rabbits, and fox	unique peeling reddish bark
SANDBAR WILLOW Salix exigua	1	H	M	25'	Y	Low: nesting	forms thickets by suckering
SILVER MAPLE Acer saccharinum	1	M	H	50'	Y	Low: nesting	good source of woody debris
SWAMP WHITE OAK Quercus bicolor	1	H	M	30'	Y	High: acorns, food for quail, turkey, grouse, woodpeckers, raccoons, opossum and deer	good choice for wet sites, important lumber tree
CHINQUAPIN Quercus muehlenbergii	1 & 2	M	M	40'	Y	High: acorns, food for quail, turkey, grouse, and deer	under used, native tree
GREEN ASH Fraxinus pennsylvanica	1 & 2	M	H	50'	Y	Medium: seeds and foliage, food for wood ducks, grosbeaks, squirrels, and deer	important lumber tree
HACKBERRY Celtis occidentalis	1 & 2	M	M	40'	Y	High: fruits and twigs, food for mourning doves, quail, squirrels, and deer	adaptable to a wide range of conditions
OVERCUP OAK Quercus lyrata	1 & 2	M	M	30'	Y	High: same as Swamp White Oak	important lumber tree
PIN OAK Quercus palustris	1 & 2	M	M	40'	Y	High: same as Swamp White Oak	bronze or red fall foliage
RED MAPLE Acer rubrum	1 & 2	H	M	40'	Y	High: seeds and sap, food for songbirds, chipmunks, and deer	red fall color and bloom
SWEET GUM Liquidambar styraciflua	1 & 2	M	H	60'	Y	Low: seeds for mourning doves, beaver, squirrels, and chipmunks	yellow-red fall color

TABLE 1 - TREES

Plant Names	Drainage Area Suitability	Tolerance to Flooding	Shade Value	Height 20 Years	Native Species	Wildlife Value	Notes
SYCAMORE Platanus occidentalis	1 & 2	M	H	60'	Y	Low: nesting cavities, seeds, food for finches, and squirrels	unique peeling bark, fast growth rate
BLACK LOCUST Robinia pseudoacacia	2	L	M	40'	Y	Low: seeds, food for some wildlife	nitrogen fixing, seeds freely and suckers
LOBLOLLY PINE Pinus taeda	2	L	M	60'	Y	Medium: seeds and sap, food for doves, woodpeckers, nut-hatches, and squirrels	recommended for coastal plain area, fast growth rate
RED OAK Quercus rubra	2	L	M	40'	Y	High: same as Swamp White Oak	excellent red fall color
WHITE OAK Quercus alba	2	L	M	30'	Y	High: same as Swamp White Oak	variable fall color, stately tree

TABLE 1 - SHRUBS

Plant Names	Drainage Area Suitability	Tolerance to Flooding	Shade Tolerance	Shade Value	Height 20 years	Native Species	Wildlife Value	Notes
BUTTONBUSH Cephalanthus occidentalis	1	H	full sun to partial shade	L	8'	Y	Medium: seeds and nectar, food for hummingbirds, ducks, beavers, and rails	unusual, round white flowers
SILKY DOGWOOD Cornus amomum	1	M	full sun to partial shade	L	10'	Y	High: berries and twigs, food for wood-peckers, pine warblers, finches, cardinals, and deer	produces fruit at 3-5 years of age
SMOOTH ALDER Alnus serrulata	1	H	partial shade	L	10'	Y	Medium: seeds, food for ducks, quail, doves and deer	nitrogen fixing
WINTERBERRY Ilex verticillata	1	M	full sun to partial shade	L	10'	Y	High: berries, food for woodpeckers, waxwings, cardinals, chickadees and deer	need male and female plants for fruit produc-tion
ARROWWOOD VIBURNUM Viburnum dentatum	1 & 2	M	full sun to partial shade	L	10'	Y	Medium: berries and foliage, food for grouse, squirrels, and deer	suckers freely, wood used to make arrows
CRANBERRY BUSH Viburnum trilobum	1 & 2	M	full sun to partial shade	L	12'	Y	Medium: same as Arrowwood Viburnum	yellow to red fall color, white flower clusters
ELDERBERRY Sambucus canadensis	1 & 2	H	full sun to partial shade	L	12'	Y	High: berries and nectar, food for wood-peckers, blue jays, grosbeaks, rabbits, and squirrels	large clusters of white flowers followed by purple berries, fast growth rate
GRAY DOGWOOD Cornus racemosa	1 & 2	L	full sun to shade	L	10'	Y	High: same as Silky Dogwood	White flowers, white berries

TABLE 1 - SHRUBS

Plant Names	Drainage Area Suitability	Tolerance to Flooding	Shade Tolerance	Shade Value	Height 20 years	Native Species	Wildlife Value	Notes
NANNYBERRY Viburnum lentago	1 & 2	L	full sun to shade	M	20'	Y	Medium: same as Arrowwood Viburnum	often suckers
PAWPAW Asimina triloba	1 & 2	M	full sun to partial shade	M	20'	Y	High: important food source for fox and opossum	suckers and forms colonies
REDOSIER DOGWOOD Cornus sericea	1 & 2	L	full sun to shade	L	8'	Y	High: same as Silky Dogwood	good for streambank stabilization
BRISTLY LOCUST Robinia hipsida	2	L	full sun to partial shade	L	8'	N	Low	nitrogen fixing, good for steep sandy slopes
NINEBARK Physocarpus opulifolius	2	M	full sun to partial shade	L	9'	Y	Low	peeling bark, hidden by dense foliage
SPICEBUSH Lindera benzoin	2	M	full sun to partial shade	L	12'	Y	Medium: berries, food for thrushes, catbirds, and kingbirds	fragrant leaves and twigs, yellow fall color

NOTE: Native refers to species that occur naturally in the state of Maryland.

TABLE 2: Zone 3 Planting

1. Native, warm-season grass mix for somewhat poorly to well drained sites

Name	Planting Rate - Pure Live Seed			
	lbs/ac	Drilled		Broadcast seeds per sq. foot
		Seeds per linear ft.	Row spacing	
SWITCHGRASS Panicum virgatum 'shelter'	8	30	36"	40
EASTERN GAMAGRASS Tripsacum dactyloides 'Pete'	10	4	36"	
OATS	20			

For added wildlife and aesthetic value add ¼ lb/ac to ½ lb/ac of a mix of 2 or more of the following:

GREAT ASTER	Aster grandiflorus	(height 2-5')
SMOOTH ASTER	Aster laevis	(height 2-5')
FALL PHLOX	Phlox paniculata	(height 2-5')
SNEEZEWEED	Helenium flexuosum	(height 2-5')
WILD BERGAMONT	Monarda fistulosa	(height 2-4')
PURPLE CONEFLOWER	Echinacea purpurea	(height 3')
MONKEY FLOWER	Mimulus alatus & M. Ringens	(height 1')
BLAZING STAR	Liatris spicata	(height 2-5')
BEE BALM	Monarda didyma	(height 2-4')
GREEN CONEFLOWER	Rudbeckia lanciniata	(height 2-8')

2. Native, warm-season grass for mix moderately well to well drained sites

Name	Planting Rate - Pure Live Seed			
	lbs/ac	Drilled		Broadcast seeds per sq. foot
		Seeds per linear ft.	Row spacing	
BIG BLUESTEM Andropogon gerardii 'niagara'	10	30	30"	40
SWITCHGRASS Panicum virgatum 'shelter'	8	30	36"	40
INDIANGRASS Sorghastrum nutans	5	30	30"	30
OATS	20			

For added wildlife and aesthetic value add ¼ lb/ac to ½ lb/ac of a mix of two or more of the following:

MARYLAND GOLDENASTER	Chrysopsis mariana	(height 1-2')
TICKSEED	Coreopsis tinctoria	(height 2-3')
WILD BLUE INDIGO	Baptisia australis	(height 3-5')
SHOWY ASTER	Aster spectabilis	(height 2-5')
BUTTERFLYWEED	Asclepias tuberosa	(height 1-2')
COMMON MILKWEED	Asclepias syriaca	(height 2-5')
WILD COLUMBINE	Aquilegia canadensis	(height 1-2')
BLACK-EYED SUSAN	Rudbeckia hirta 'golden jubilee'	(height 2-3')

NOTE: On slopes greater than 6% plant a cover crop in the fall, cut in the spring and no-till warm season grass seed into the stubble.

TABLE 2: Zone 3 Planting			
For each of the following mixes, add one of these crops: Winter Rye 20 lbs/ac Winter Wheat 20 lbs/ac Spring Oats 20 lbs/ac			
3. Cool-season grass and legume mix for well drained sites: *(This is a non-competive mix and can be used to stabilize areas where trees and shrubs will be planted.)*			
Name		**Lbs/Ac**	**Planting Date**
CREEPING RED FESCUE	Festuca rubra	10	early spring or fall
HARD FESCUE	Festuca longifolia	10	early spring or fall
WHITE CLOVER	Trifolium repens	2	early spring or fall
Cool-season grass and legume mix for poorly drained sites:			
REED CANARY GRASS	Phalaris arundinacea	10	spring
BIRDSFOOT TREFOIL	Lotus corniculatus	6	
4. Cool-season grass mix for moderately well drained sites			
Name		**Lbs/Ac**	**Planting Date**
KENTUCKY BLUEGRASS	Poa pratensis	25	spring or fall
PERENNIAL RYEGRASS	Lolium perenne	15	spring or fall
RED TOP	Argostis gigantea	5	spring or fall
5. Cool-season grass & wildflower mix for moderately well to excessively drained sites			
Name		**Lbs/Ac**	**Planting Date**
CHEWINGS FESCUE	Festuca rubra L. Ssp. falax	10	spring or early fall
HARD FESCUE	Festuca longifolia	10	spring or early fall
WILDFLOWER SEED MIX (Choose 4 or more species from wildflowers in mix 2)		6	

OPERATION AND MAINTENANCE

The following actions shall be carried out to insure that this practice functions as intended throughout its expected life. These actions include normal repetitive activities in the application and use of the practice (operation), and repair and upkeep of the practice (maintenance):

The riparian forest buffer will be inspected periodically, protected and restored as needed, to maintain the intended purpose from adverse impacts such as excessive vehicular and pedestrian traffic, pest infestations, pesticide use on adjacent lands, livestock damage and fire.

Replacement of dead trees or shrubs and control of undesirable vegetative competition will be continued until the buffer is, or will progress to, a fully functional condition.

As applicable, control of concentrated flow erosion or mass soil movement shall be continued in the up-gradient area immediately adjacent to zone 2 to maintain buffer function.

Any removals of tree and shrub products shall be conducted in a manner that maintains the intended purpose and is consistent with state and local law.

For purposes of moderating water temperatures and providing detritus and large woody debris, riparian forest buffer management must maintain a minimum of 50 percent canopy cover. To achieve benefits provided by large woody debris, natural mortality of trees and large shrubs may need to be supplemented by periodically falling and placing selected stems or large limbs within water courses and water bodies to reach original design specifications.

For providing habitat and corridors for wildlife, manage the buffer to favor food, shelter and nesting cover that would satisfy the habitat requirements of the indicator or target wildlife species. Refer to MD Wildlife Biology and Management Handbook for more information.

For purposes of reducing excess pollutants in surface runoff and shallow groundwater (zone 1 and 2), or providing habitat and corridors for wildlife (zone 1 at a minimum), manage the dominant canopy to maintain maximum vigor of overstory and understory species.

Weeds should be controlled for 2 - 3 years after planting. Any use of fertilizers, mechanical treatments, prescribed burning, pesticides and other chemicals to assure buffer function shall not compromise the intended purpose. *Biological control of undesirable plant species and pests (e.g., using predator or parasitic species), shall be implemented where available and feasible.*

Additional operation and maintenance requirements shall be developed on a site-specific basis to assure performance of the practice as intended.

DATA AND SUPPORTING DOCUMENTATION

The following is a list of information to be recorded in the case file.

1) Purpose of riparian forest buffer

2) Field location and plan view

3) Size of planting

   - width of floodplain (ft)
   - width of planting (ft)
   - length of stream (ft)
   - acres of riparian forest buffer

4) Planting details

   - date planted
   - species planted
   - spacing of planting

5) Operation and maintenance plan

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MINIMUM BUFFER WIDTHS FOR SPECIFIC PURPOSES

- To create shade to moderate water temperatures and improve habitat for fish and other aquatic organisms.

  35 feet minimum

- Provide a source of detritus and large woody debris for fish and other aquatic organisms.

  35 feet minimum

MINIMUM BUFFER WIDTHS FOR SPECIFIC PURPOSES

- To provide riparian habitat and corridors for wildlife.

  Specific widths are listed in the standard for some wildlife species. These are total combined buffer widths. (Ex. 100 feet for frogs and salamanders, 300 feet for neotropical migrants.)

- To reduce excess amounts of sediment organic material, nutrients, pesticides and other pollutants in surface runoff and reduce excess nutrients and other chemicals in shallow ground water flow.

  100 feet or 30 percent of the geomorphic floodplain whichever is less, but not less than 35 feet wide. For a 150 foot floodplain, the minimum required is 45 feet. (Calculation 150 ft. x .30 = 45 feet.)

United States
Department of
Agriculture

Forest Service

Northeastern Area
State & Private Forestry

Forest Resources
Management

Radnor, PA

NA-PR-07-91

RIPARIAN FOREST BUFFERS

Function and Design for Protection and Enhancement of Water Resources

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RIPARIAN FOREST BUFFERS

Function and Design for Protection and Enhancement of Water Resources

Prepared by
David J. Welsch

Forest Resources Management
Northeastern Area
State and Private Forestry
USDA Forest Service
Radnor, Pennsylvania

The United States Department of Agriculture (USDA) Forest Service wishes to thank the following organizations for their assistance in the preparation of this document.

The United States Department of Agriculture (USDA) Agricultural Research Service

The United States Department of Agriculture (USDA) Soil Conservation Service

Stroud Water Research Center, Academy of Natural Sciences of Philadelphia

Pennsylvania Department of Environmental Resources, Bureau of Forestry

Maryland Department of Natural Resources, Forest Park and Wildlife Service

The United States Department of Interior (USDI) Fish and Wildlife Service

Cover: A natural riparian forest provides excellent protection for water resources.

Ed Callahan Maryland Department of Natural Resources

Streamside forests are complex ecosystems vital to the protection of our streams and rivers

Streamside forests are crucial to the protection and enhancement of the water resources of the Eastern United States. They are extremely complex ecosystems that help provide optimum food and habitat for stream communities as well as being useful in mitigating or controlling nonpoint source pollution (NPS). Used as a component of an integrated management system including nutrient management and sediment and erosion control practices, streamside forests can produce a number of beneficial effects on the quality of water resources. Streamside forests can be effective in removing excess nutrients and sediment from surface runoff and shallow groundwater and in shading streams to optimize light and temperature conditions for aquatic plants and animals. Streamside forests also ameliorate the effects of some pesticides, and directly provide dissolved and particulate organic food needed to maintain high biological productivity and diversity in the adjoining stream.

Ed Callahan · Maryland Department of Natural Resources

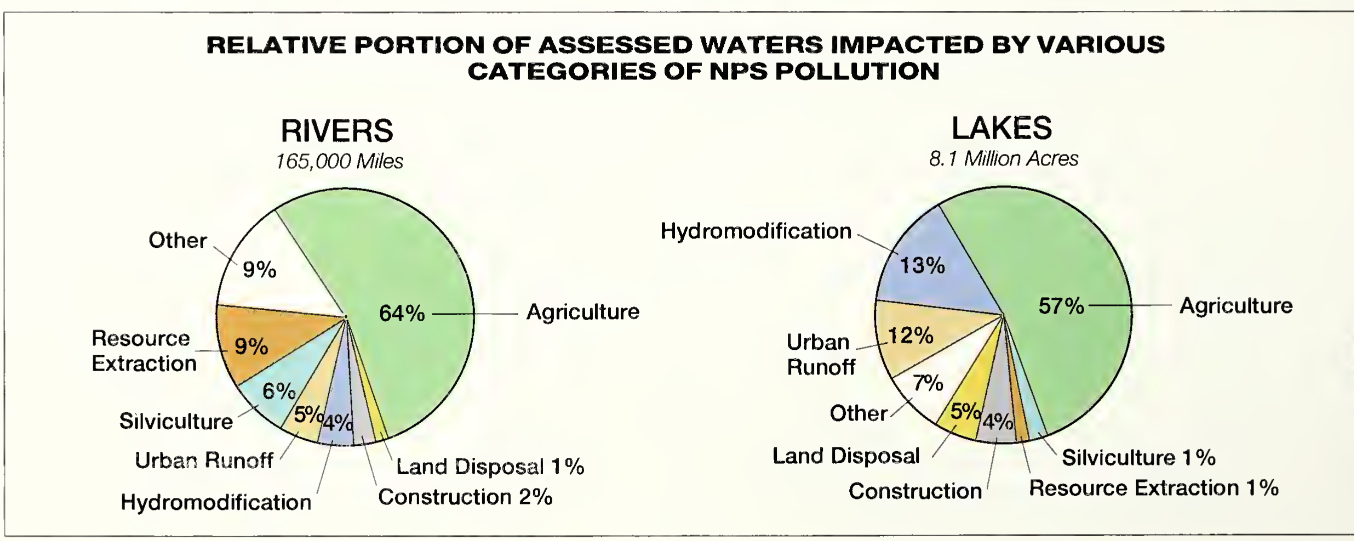
▲ *Streamside forests are crucial to water resource protection.*

USDA Forest Service

▲ *Forested watersheds are the generally accepted benchmark of quality for water resources.*

USDA Soil C vation Service

▲ *Deforestation associated with agricultural expansion has left our waters vulnerable to pollution from animal waste and fertilizer.*



Reference: 1985. America's Clean Water: The State's Evaluation of Progress.

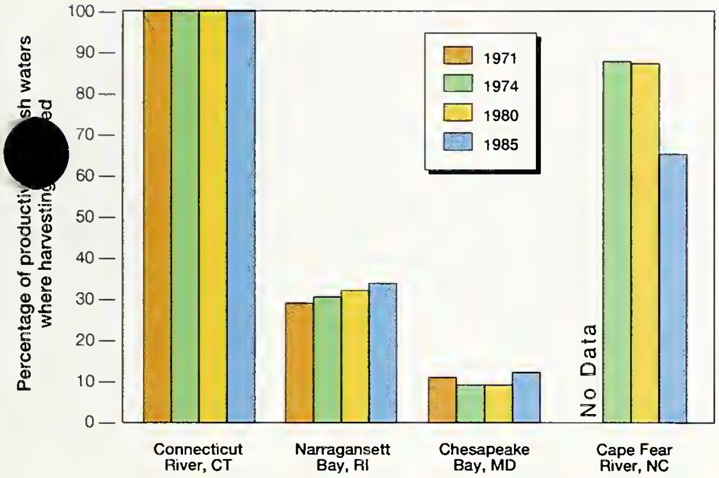
USDA Soil Conservation Service

▲ *Many of America's waters have been rendered unfit for use.*

The removal of streamside forests has adversely affected the vitality of our water resources

In natural conditions, streamside forests protected most of the rivers and streams of our nation, but deforestation associated with agricultural and urban expansion has drastically reduced the extent of streambank protected by forest. The result has been an adverse effect on the quality of water and aquatic habitats. In many of our streams and estuaries, water is unfit for human consumption, industrial use or recreation. Shellfish and finfish production is also reduced. These problems are linked, in part, to contamination from nutrients, sediment, animal waste, and other pollutants associated with agricultural and urban runoff.

HARVEST–LIMITED SHELLFISH WATERS FOR SELECTED ESTUARIES, 1971-1985



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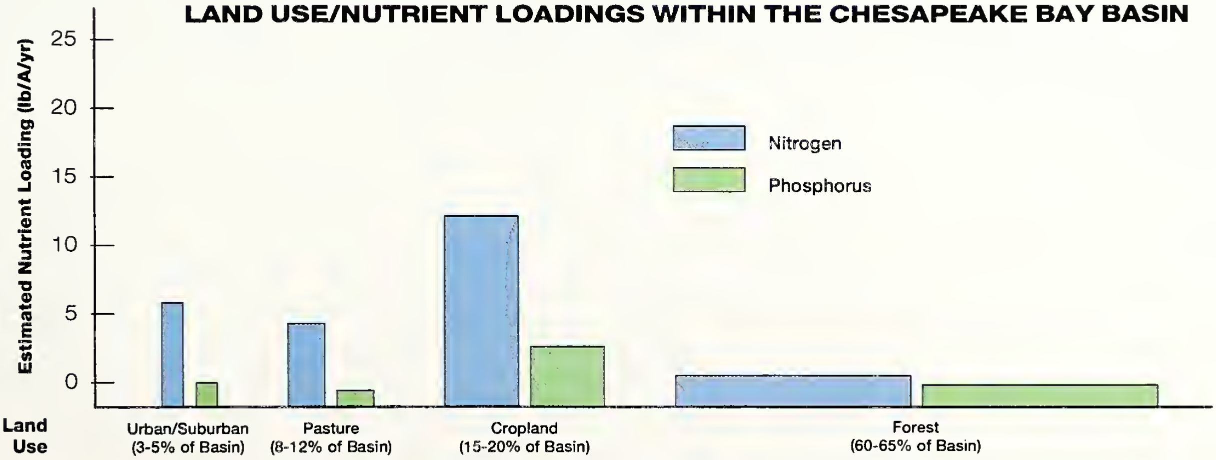
LAND USE/NUTRIENT LOADINGS WITHIN THE CHESAPEAKE BAY BASIN



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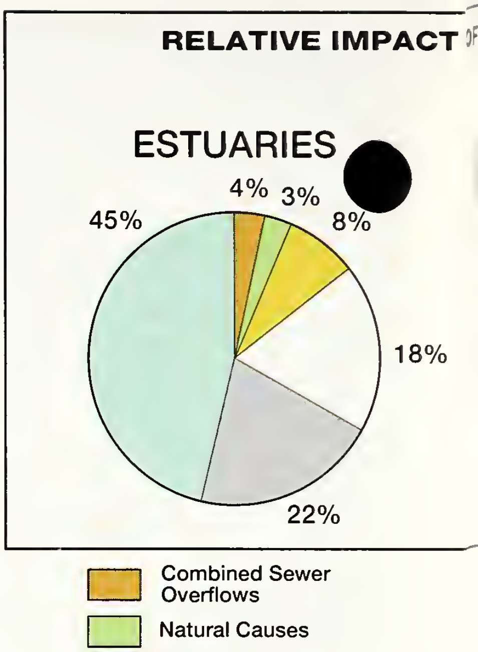
Continued Strengthening of the Clean Water Act Reflects the Public's Concern for Clean Water

The Water Pollution Control Act of 1948 or "Clean Water Act" and its subsequent amendments through 1987 demonstrate strong congressional determination to improve the quality of our water resources. These laws have done much to clean up point source contaminants by requiring states to establish and enforce water quality standards, by requiring specifications and licensing for the discharge of effluents, and by funding the installation of municipal sewage treatment plants. As a result of the cleanup of concentrated pollution from specific sites, nonpoint source pollutants, which are typically dispersed in origin, have increased in relative importance and now account for more than 50% of the pollution in our nation's waters. Nonpoint source pollutants include sediment, nutrients, pesticides, animal wastes and other substances which enter our water supply as components of runoff and groundwater flow.



Excess Nitrogen and Phosphorus Spur Algal Growth, Deplete Oxygen and Kill Fish

Aquatic plants, like their terrestrial counterparts, require nutrients to grow and reproduce. The growth of algae and other vegetation in water bodies is usually controlled by the nutrient whose supply is most limited. This concept, first described by Justis Liebig in 1840, is known as "Liebig's Law of the Minimum". Phosphorus is usually the limiting nutrient in brackish or freshwater, while nitrogen is usually the limiting nutrient in saltwater. When excess nutrients applied to the land in the form of manure or commercial fertilizer find their way into the water, blooms or overabundant growth of algae and other aquatic plants can result. Algal blooms at the surface can interfere with photosynthesis of submerged plants by blocking sunlight, causing them to die. When this happens, dissolved oxygen levels near the bottom drop abruptly because oxygen demand by decomposing bacteria is great while little or no oxygen is being produced by the dying plants. The problem is compounded when organisms which flourish in oxygen starved environments release hydrogen sulfide and methane. These substances are toxic to fish and other aquatic life.

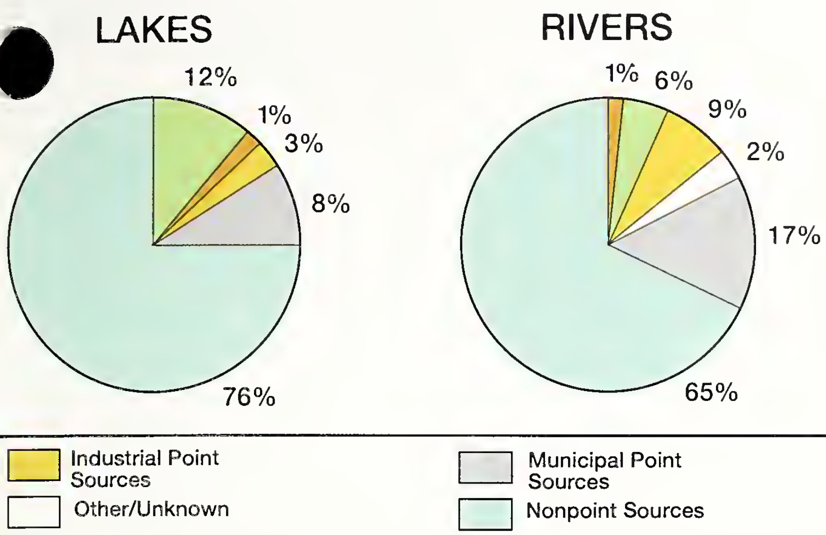
George Eberling Maryland Department of Natural Resources

▲ *Dense algal growth from excess nutrients blocks sunlight, causing submerged plants to die.*

Excessive algal growth in estuaries can result in the decline of Eelgrass and the loss of shellfish beds. Shellfish die and the beds fail to recolonize when thick layers of algae prevent animals such as oysters from pumping water through their bodies to provide adequate food and oxygen. Eelgrass, a submerged grass eaten by many waterfowl, is lost when floating algal mats and or phytoplankton in the water reduce light penetration and interfere with photosynthesis.

Some species of fish, as well as other animals lower in the food chain are very sensitive to low levels of oxygen or food and generally die. The loss of species simplifies the food chain of an ecosystem and makes it more vulnerable to further destruction.

OF NONPOINT SOURCE POLLUTION PROBLEMS IN IMPAIRED WATERS



Reference: 1989. Environmental Trends, Council on Environmental Quality.

Streamside Forests Remove Pollutants in Several Ways

Recent research has shown that streamside forests can: 1) improve the quality of water resources by removing or ameliorating the effects of pollutants in runoff and 2) increase the biological diversity and productivity of stream communities by improving habitat and adding to the organic food base. Streamside forests function, often simultaneously, as **FILTERS, TRANSFORMERS, SINKS** and **SOURCES**.

Phil Pannill Maryland Department of Natural Resources

▲ *Aquatic grasses are important to the food web.*

USDA Forest Service

▲ *Many species, including fish, are sensitive to low oxygen levels and die as a result.*

Excess Nitrogen in Drinking Water is Detrimental to Children and Livestock

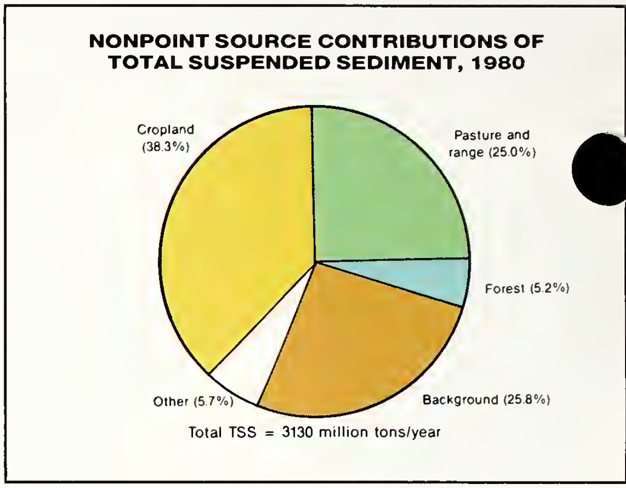
Excess nitrogen, in surface and groundwater systems used for drinking water, is dangerous to the health of certain groups of people and animals. For example, infants less than six months old are particularly susceptible to harm because their stomachs are not acidic enough to prevent the growth of certain bacteria which convert nitrate to nitrite. High levels of nitrites can oxidize hemoglobin to form methanoglobin which is unable to carry oxygen. Brain damage or death by suffocation can result from this condition known as methemoglobinemia or blue baby syndrome.

Pregnant cows can also suffer from methemoglobinemia, which usually results in death of the newborn calf.

The allowable level of nitrogen in water for children six months of age or less is 10 ppm (10 mg/1) as nitrate nitrogen or 45 ppm (45 mg/1) as nitrate. Adults and older children can probably tolerate higher levels, but the standard is usually set at the more conservative level. Should ground water become contaminated, nitrate removal at a community treatment plant is presently estimated to cost about \$10 to \$15/month for a family of three.

The Streamside Forest Removes Sediment and Sediment-Attached Phosphorus by Filtration

The streamside forest functions as a FILTER by removing sediment and other suspended solids from surface runoff. Sediment is probably the most common and most easily recognized of the nonpoint source pollutants.



Reference: 1989. Environmental Trends, Council on Environmental Quality.

USDA Soil Conservation Service

▲ *Agricultural runoff can carry sediment, nutrients and pesticides to surface waters.*

Cropland erosion accounts for about 38% of the approximately 1.5 billion tons of sediment that reach the nation's waters each year. Pasture and range erosion accounts for another 26%.

Sediment suspended in the water can reduce or block the penetration of sunlight, adversely affecting the growth and reproduction of beneficial aquatic plants.

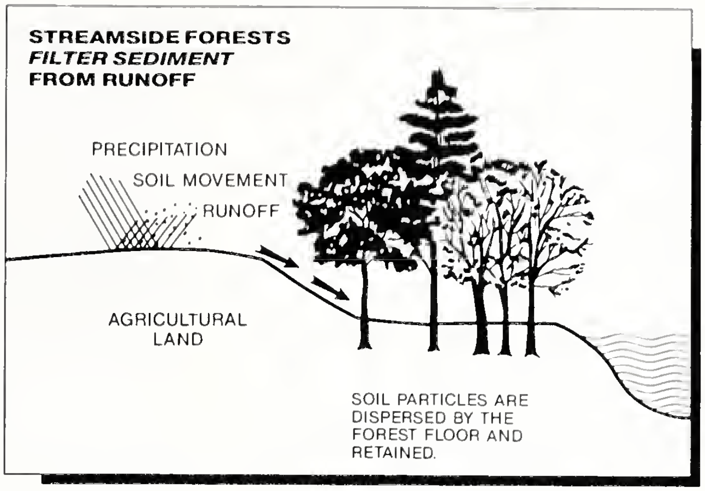
Sediment deposited on the stream bottom can interfere with the feeding and reproduction of bottom dwelling fish and aquatic insects, weakening the food chain. Large deposits of sediment can overfill stream channels and floodplains, greatly increasing the potential for flooding.

USDA Soil Conservation Service

▲ *Sediment is the most easily recognized of the nonpoint source pollutants.*

George Eberling Maryland Department of Natural Resources

▲ *Streambank erosion also contributes to stream sediment load.*

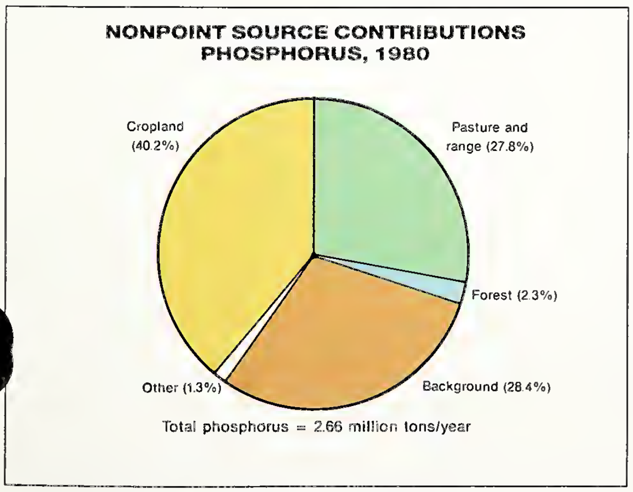


Reference: Maryland Department of Natural Resources

Several mechanisms of sediment removal are at work in the streamside forest. Some sediment settles out as the speed of the flow is reduced by the many obstructions encountered in the forest litter. Additional sediment is filtered out by the porous soil structure, vegetation and organic litter as the runoff flows over and into the floor of the streamside forest.

Phosphorus is also reduced by the filtering action of the streamside forest because about 85% of available phosphorus is bonded to the small soil particles comprising the sediment. Approximately 4% of the phosphorus is attached to soil particles too small to be filtered by these processes resulting in a removal of about 80% of phosphorus by the riparian forest filter. The minor amount of ammonium which is bound to sediment can be filtered out in the same way.

However, dissolved phosphorus and nitrate must be removed by either microbial or biochemical transformation processes.



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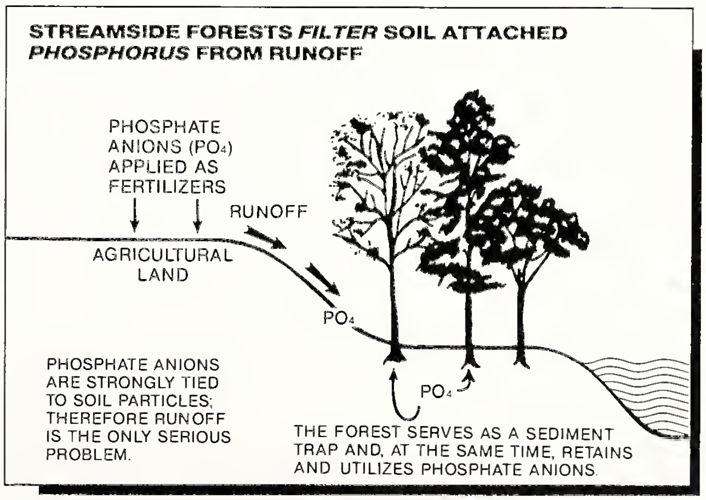


Reference: Maryland Department of Natural Resources

The Streamside Forest Transforms Nitrate to Nitrogen Gas

USDA Soil C ation Service

▲ *Excess nitrogen from animal waste can reach streams with runoff.*

The streamside forest functions as a TRANSFORMER when chemical and biological processes occurring within it change the chemical composition of compounds. For example, under well oxygenated soil conditions, bacteria and fungi in the streamside forest convert nitrogen in runoff and decaying organic debris into mineral forms (NO_3). These forms can then be synthesized into proteins by plants or bacteria. When soil moisture is high enough to create anaerobic conditions in the litter and surface soil layers, denitrifying bacteria convert dissolved nitrogen into various nitrogen gasses, returning it to the atmosphere. Studies have shown that the amount of nitrogen in runoff and shallow groundwater can be reduced by as much as 80% after passing through a streamside forest.

The streamside forest can also function as a TRANSFORMER when toxic chemicals such as pesticides are converted to non-toxic forms. Because of continued improvements in the for-

Nature Provides Safe Storage for Nutrients in Biological Cycles

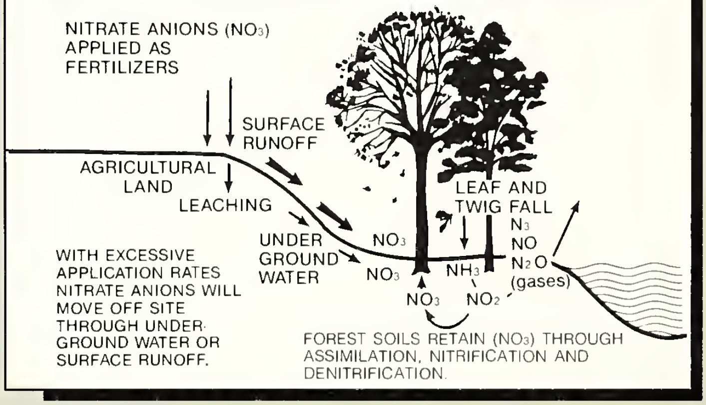
The basic elements that occur in nature move through the environment in a series of naturally occurring chemical and biological states, a process commonly referred to as a cycle. The cycle describes the state, chemical form, and relative abundance of the element at each point along its route through the environment. There is usually a state, chemical form, and location in the cycle in which nature safely stores the bulk of the element. In the case of the nitrogen cycle, the bulk is stored as nitrogen gas in the atmosphere. Pollution occurs when, through man's interference, an element occurs at some point in the cycle in an inappropriate form or amount, thus disrupting the environmental balance.

Nitrogen and phosphorus, elements essential to plant growth, move through the environment in such cycles. Fertilizers and animal wastes both contain nitrogen and phosphorus. When these elements are applied to crop and pasture lands in amounts in excess of plant needs, they can adversely affect water quality.

Phosphorus, the less mobile of these two nutrients, is quickly bound to soil particles or taken up by plants. Becau about 85% of phosphorus is bound to soil and organic particles, eroding sediments and organic materials borne by runoff are the chief sources of phosphorus in water.

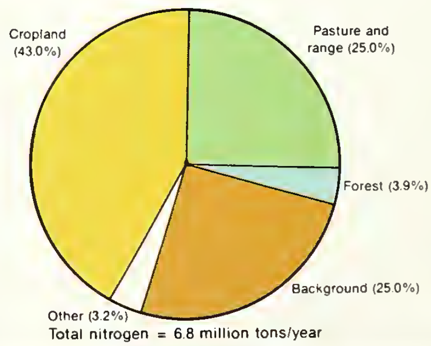
In contrast, nitrogen from fertilizer and animal waste is soluble in water as nitrate, and not held by soil particles. Nitrate ions, which are not taken up by plants or converted to gaseous forms by microbial action, can leach downward through the soil into the groundwater or move laterally with surface and subsurface flow to contaminate surface waters.

STREAMSIDE FORESTS *TRANSFORM NITROGEN* IN RUNOFF TO GAS OR USE IT IN GROWTH PROCESSES

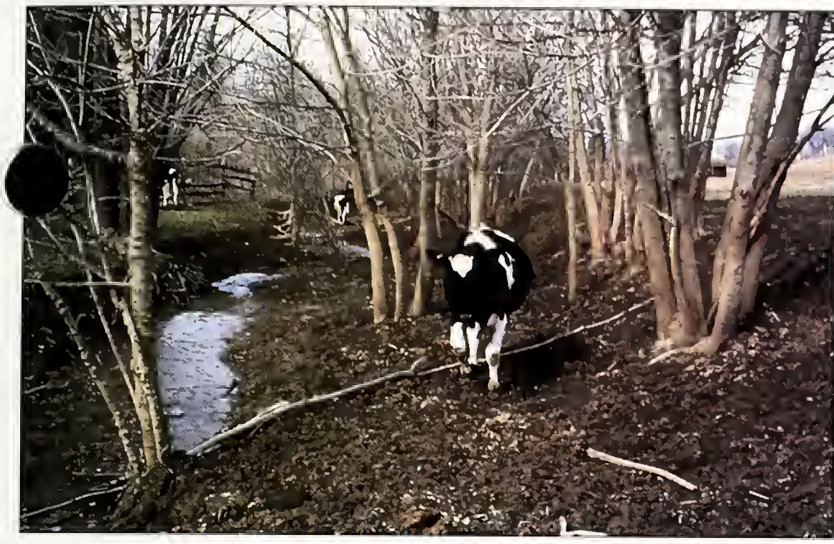


Reference: Maryland Department of Natural Resources

NONPOINT SOURCE CONTRIBUTIONS NITROGEN, 1980



Reference: Maryland Department of Natural Resources



▲ Cattle-trodden and grazed streambanks offer little protection from runoff and associated pollutants.

▲ Careful metering of fertilizer and pesticides and minimum tillage methods help reduce nonpoint source pollution.

mulation and management of pesticides, only very small amounts manage to leave the area of application. These residues, borne by runoff, are converted to non-toxic compounds by microbial decomposition, oxidation, reduction, hydrolysis, solar radiation and other biodegrading forces at work in the soil and litter of the streamside forest. While scientists have long understood the biological processes at work in the streamside forest, additional data are necessary to fully quantify their importance with respect to pesticide degradation.

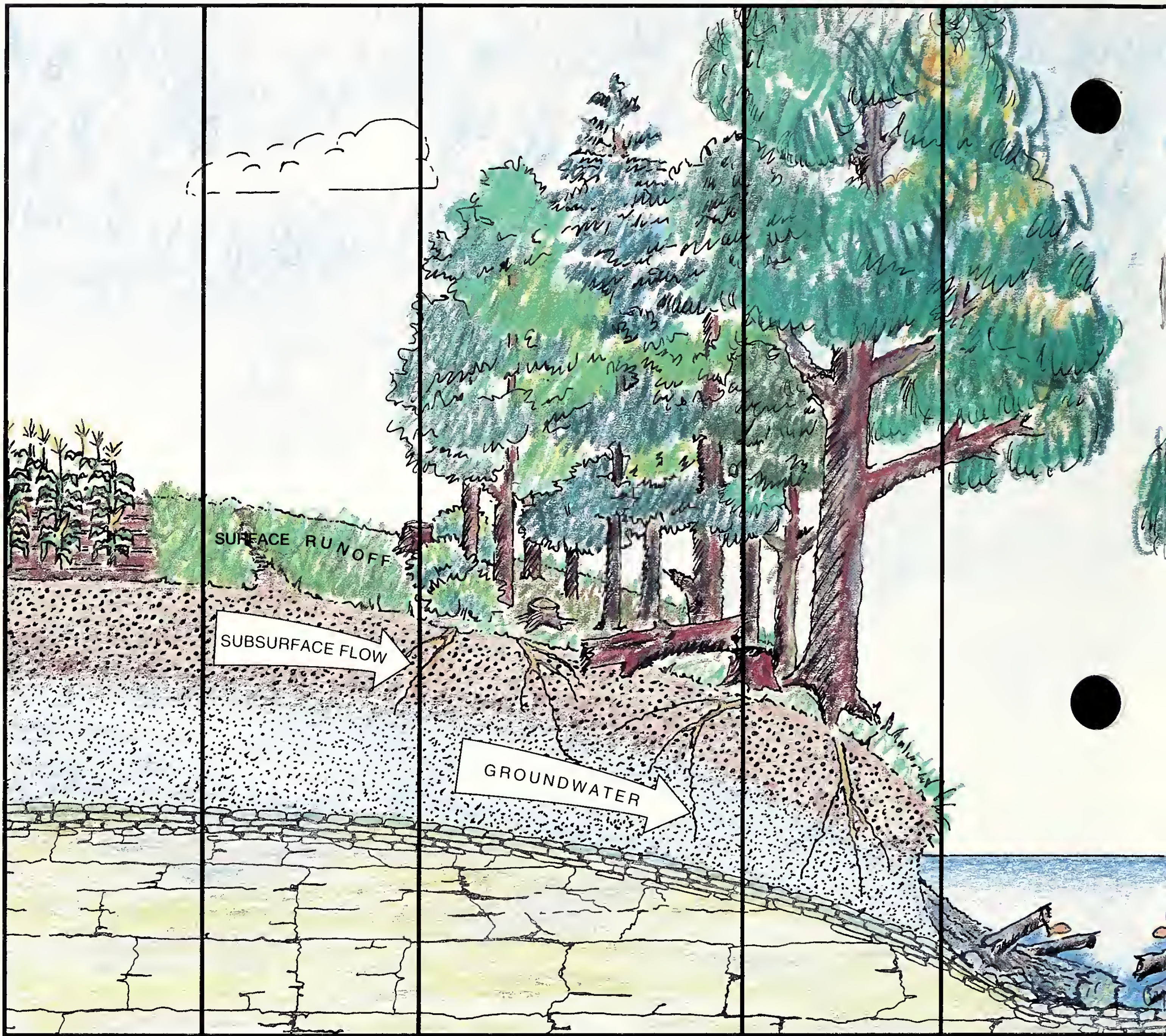
...chnological Improvements Have Reduced the Impact of ...sticides on the Aquatic Environment

The chemical, physical and biological properties which determine the effect of pesticides on water resources and the fate of these pesticides in the environment have been advanced significantly in the years since Rachel Carson's "Silent Spring". Wide spectrum pesticides, which kill a wide variety of non-target organisms and remain active for a long period of time, are no longer used. For example, DDT is a wide spectrum chlorinated hydrocarbon with a half life of ten years (i.e. the time required for one-half of a compound to decay). DDT, and other pesticides like it, have been banned in the United States because they concentrate in fatty tissue and tend to accumulate in the food chain where they can interfere with the reproduction and survival of many non-target species.

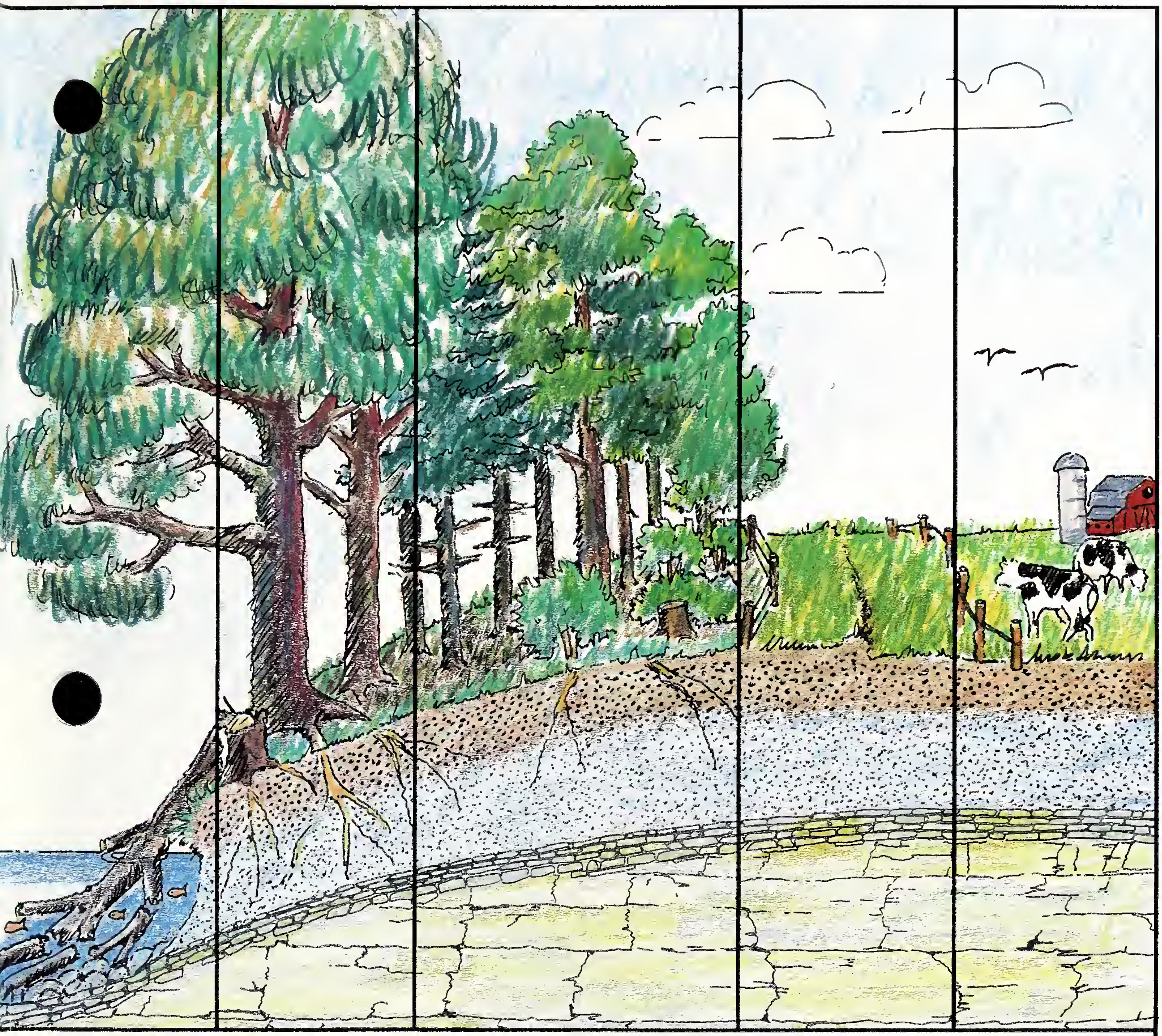
▲ Large droplet sprayers and low level application help to control placement of pesticide.

Many contemporary insecticides such as Organophosphate and Carbamate have half lives of only a few days to several weeks, are not fat soluble, and are often much more specific in the targets they affect. While these insecticides do not accumulate up the food chain and are safer environmentally, they are very soluble in water and usually quite toxic to fish.

In contrast, most herbicides currently in use break down by the end of the growing season and are relatively less toxic to fish than insecticides. However, if herbicides reach surface waters, many species of aquatic plants can be killed. Along with shorter half lives, newer pesticides utilize more effective stickers (the chemicals which keep them in place) and are thus effective in much lower concentrations. This makes them easier to control and adds less chemical to the environment. In addition, biological controls (viruses and bacteria that occur in nature) are being refined and adopted for use as natural microbial pesticides, such as Bacillus thuringiensis for the control of gypsy moth.



	20'	60'	15'	
CROPLAND	**ZONE 3 RUNOFF CONTROL**	**ZONE 2 MANAGED FOREST**	**ZONE 1 UNDISTURBED FOREST**	**STREAM**
Sediment, fertilizer and pesticides are carefully managed.	Concentrated flows are converted to dispersed flows by water bars or spreaders, facilitating ground contact and infiltration.	Filtration, deposition, plant uptake, anaerobic denitrification and other natural processes remove sediment and nutrients from runoff and subsurface flows.	Maturing trees provide detritus to the stream and help maintain lower water temperature vital to fish habitat.	Debris dams hold det by aquatic fauna and cooling shade for fish dwellers.



	← 15' →	← 60' →	← 20' →	
AM BOTTOM	ZONE 1 UNDISTURBED FOREST	ZONE 2 MANAGED FOREST	ZONE 3 RUNOFF CONTROL	PASTURE
detritus for processing nd provide cover and sh and other stream	Tree removal is generally not permitted in this zone.	Periodic harvesting is necessary in Zone 2 to remove nutrients sequestered in tree stems and branches and to maintain nutrient uptake through vigorous tree growth.	Controlled grazing or haying can be permitted in Zone 3 under certain conditions.	Watering facilities and livestock are kept out of the Riparian Zone insofar as practicable.

The Streamside Forest Acts as a Sink by Storing Nutrients for Extended Periods of Time

The streamside forest can function as a SINK when nutrients are taken up by plants and sequestered in plant tissue. Some estimates indicate that 25% of the nitrogen removed by the streamside forest is assimilated in tree growth which may be stored for extended periods of time in woody tissue and possibly removed as logs or other forest products. Nitrogen and other nutrients may also be passed up the food chain when plant tissues are consumed by animals and converted to animal tissues. In wetter areas, nutrients in leaf litter can be stored for longer periods as peat. Sediments filtered out by the streamside forest remain to become incorporated into the forest soil.

George Eberling Maryland Department of Natural Resou...

▲ *Nutrients can be filtered, transformed or stored by processes taking place in the forest litter.*

The Streamside Forest Provides a Source of Energy for Aquatic Life

The streamside forest functions as a SOURCE when it provides energy to streams in the form of dissolved carbon compounds and particulate organic detritus. These materials are critical to processes within the stream itself, helping to restore and maintain nature's equilibrium. In small, well-shaded upland streams, as much as 75% of the organic food base may be supplied by dissolved organic compounds or detritus such as fruit, limbs, leaves and insects that fall from the forest canopy. Benthic detritivores (the stream bottom bacteria, fungi and invertebrates that [illegible] on the detritus) form the basis [illegible] the aquatic food chain. They pass on this energy when they are, in turn, consumed by larger benthic fauna and eventually by fish. Thus the streamside forest functions as an important energy source for the entire aquatic food chain from headwaters to estuary.

David Funk

▲ *Energy for aquatic life is added to streams in the form of leaves and twigs, a part of the mixture called detritus.*

Insects, the Favorite Food of Trout, are Abundant in Stream Reaches Cooled by Streamside Forests...

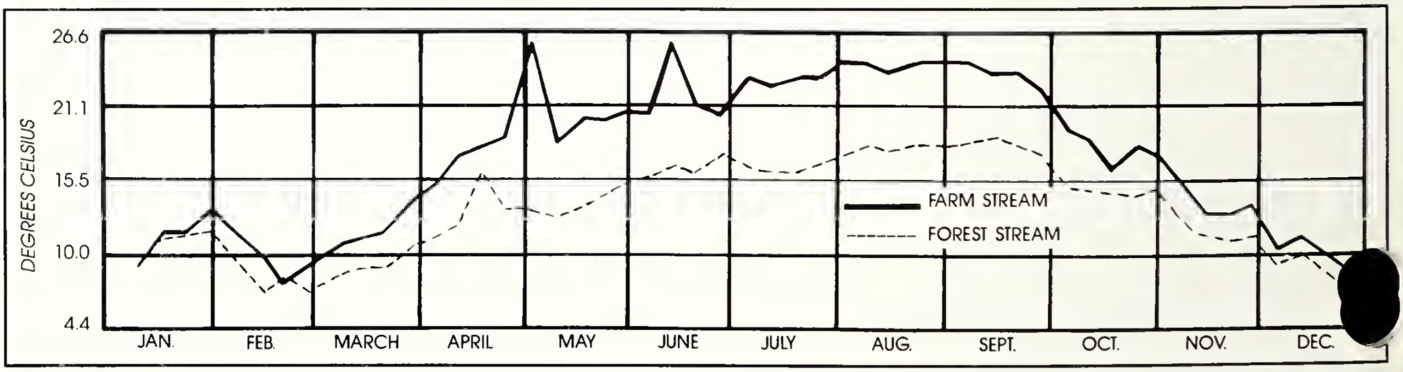
Water temperature, habitat structure, food availability and sediment flux are four important factors influencing the survival of trout (Salmonids) and other fish that are directly affected, to a large extent, by streamside forests.

In most small streams and rivers, the seasonal pattern of water temperature, the first of these factors, is determined largely by the extent that direct solar radiation and air temperature can modify the temperature of the water. In a given region, groundwater stays fairly constant in temperature throughout the year (± 1 degree C of mean annual air temperature for the region) and provides most of the baseflow for stream systems. Loss of shade from streamside forests can greatly warm streams, increasing a trout's demand for dissolved oxygen and, at the same time, reducing the amount of dissolved oxygen available in the water.

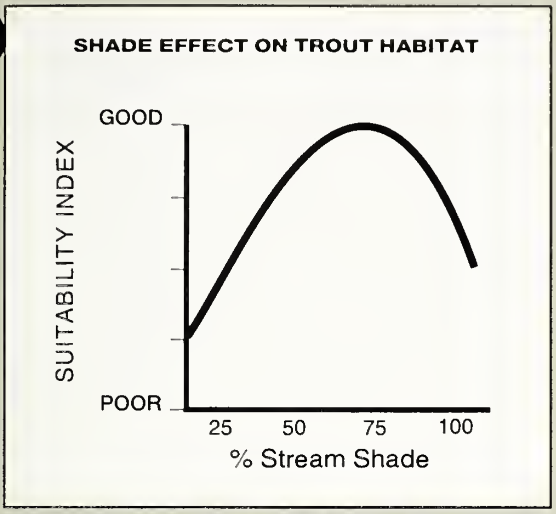
Headwater streams of first to third order

▲ *Quality water resources, as evidenced by a natural, healthy headwater stream.*

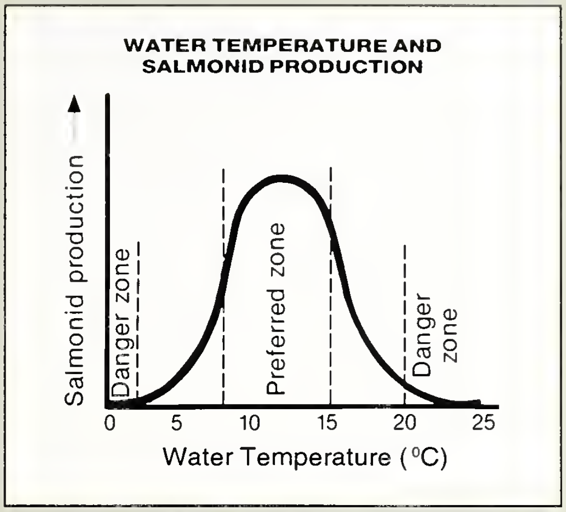
WEEKLY MAXIMUM TEMPERATURE FOR THE FARM AND FOREST STREAM



Reference: G. F. Greene, 1950. Land Use and Trout Streams, Journal of Soil and Water Conservation.



Reference: Raleigh, R.F.; Hickman, T.J.; Nelson, K.L; Maughan, O.E. 1980. Riverine habitat evaluation procedures for rainbow trout.



Reference: Everest, F.H.; Harr, D.H. 1982. Influence of forest and rangeland management on anadromous fish habitat in Western North America.

comprise about 85% of the total length of running waters, and because of the ratio of stream bottom to shoreline, are readily influenced by exposure to [illegible] energy. Agricultural drainage systems which intercept cool groundwater and drain it to streams in unshaded ditches contribute significantly to the increase in stream temperature.

Manipulation of the streamside forest canopy can be used to moderate and stabilize stream temperature to optimize the survivorship, growth, and reproductive needs of fish and aquatic macro-invertebrates and even benthic algae.

Habitat structure, the second factor affecting Salmonid survival, is enhanced by the addition to the stream channel of large woody debris which forms pools and important rearing areas. This debris also provides cover from predators and protection from high flows.

To understand the third factor, food availability, the natural stream must be viewed as a continuum from headwaters to mouth with a significant amount of the energy for aquatic life coming from organic material such as leaves, twigs, flowers, animals and insects originating from the streamside forest. These kinds of materials dominate the food base of small headwater streams flowing through forests. The food supports a diverse invertebrate community which, in turn, provides the principal food source for Salmonids in healthy ecosystems. Large amounts of leaf litter and other coarse organic matter enter small forested headwater streams and are rapidly consumed by aquatic invertebrates. These animals function as shredders because they reduce large pieces of organic debris to smaller pieces which move downstream and can be used by other animals who feed by filtering or gathering these fine particles of food.

David Funk

David Funk

▲ *Mayfly nymphs and Mayfly adults are both primary trout foods and important components of the food web.*

...Streamside Forests Control Habitat-Damaging Sediments and Provide Organic Energy to Downstream Reaches

As stream channels get wider in a downstream direction, the widening partition between the streamside forest canopies allows sufficient light to promote the growth of benthic algae, especially diatoms. Many species of invertebrates known collectively as "grazers" specialize in eating diatoms and, in turn, provide important food to fish. In large rivers that are very wide and deep, planktonic algae can become the dominant food resource with forest litter being less important.

Stephen J. Brady

▲ *A well-washed gravel stream bottom is necessary for Salmonid spawning beds.*

George Eber[illegible]land Department of Natural Resources

▲ *Well developed root systems help stabilize stream banks.*

John Dickerson USDA Soil Conservation Service

▲ *An example of a sediment-laden branch entering a less turbid stream.*

The downstream changes in channel size and shape and the organic food base along the river continuum greatly affect the fish population. For example, fish populations change from invertebrate-eating Salmonid fishes, such as trout and salmon, in the headwaters to plankton-feeding Cyprinids and Catostomids, such as carp and suckers, in large rivers.

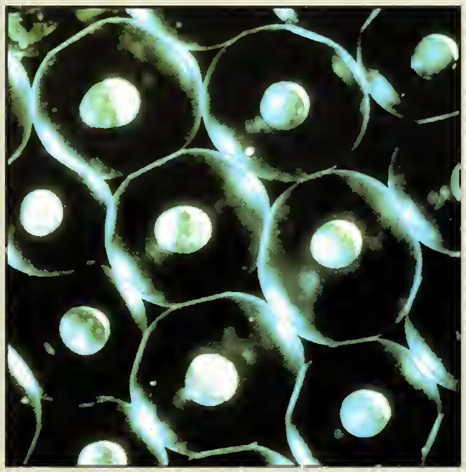
Streamside forests facilitate the downstream flow of food by contributing large stable debris to the streambed. This stable debris is the mechanism by which the detritus is held long enough to be processed by the invertebrate community. Without debris dams, much of the organic input from streamside vegetation would be washed downstream without contributing to the life processes of the aquatic food chain. Only as the streamside forest nears maturity, is it able to produce organic debris in sufficient size and quantity to provide relatively stable detritus catchments.

The streamside forest helps to control sediment flux, the fourth factor affecting Salmonid survival, by stabilizing streambanks. Sediment concentrations must be very high (above 20,000 ppm) to cause mortality in adult fish by clogging the gill filaments and preventing normal water circulation and aeration of the blood. However, abrasion damage to gills begins to occur at sediment concentrations as low as 200 ppm.

In addition, low concentrations can cause behavioral changes and disrupt normal reproduction by covering spawning grounds and preventing the emergence of recently hatched fry. Sediment covering spawning grounds reduces the flow of intragravel water, limiting oxygen availability to incubating eggs and newly-hatched alevins and hindering removal of metabolic wastes. It similarly affects aquatic insect habitat, thus altering species composition of a major trout food source. Large instream debris can help store sediment, moderating transport rates and buffering against rapid changes in sediment loads that could cover spawning gravels, fill rearing pools and reduce invertebrate populations.

USDA Forest Service

▲ *Increased stream sediment concentrations cause behavioral changes in fish and can result in migration, reduced reproduction and/ or death of a species.*



USDA Forest Service

▲ *Incubating eggs.*

USDA Forest Service

▲ *A juvenile Salmonid.*

Establishment Guidelines

Simple removal of nonpoint pollutants is not enough to improve the quality of water resources. A balanced, integrated, adaptive community of riparian and aquatic organisms comparable to the natural systems of the region with stability and capacity for self repair must be reestablished. The restoration of a healthy aquatic ecosystem from the headwaters to the estuaries to the oceans requires the reestablishment of significant amounts of riparian forest.

Control of point source pollutants was a start; control of nonpoint pollutants and repair of the aquatic ecosystem through reestablishment of the streamside forest is a logical next step in improving the quality of our water resources.

Specifications for such a streamside forest should consider the following:

1. Streamside forests should be used in conjunction with sound land management systems that include nutrient management and sediment and erosion control.
2. Sediment removal - The streamside forest must be wide enough to filter sediment from surface runoff. Maximal effectiveness depends on uniform shallow overland flow. Percent removal of Total Suspended Solids is a good indicator of effectiveness.
3. Nutrient removal - Periodic flooding and the presence of forest litter contribute to conversion of nitrate to gaseous nitrogen by denitrification. Plant uptake also accounts for significant removal of nitrogen. Trees must be removed periodically to remove nutrient sequestered in woody biomass and to maintain system efficiency.
4. Periodic minor ground shaping

▲ *Remaining riparian forests must be preserved and extended.*

natural systems of the region with stability and capacity for self repair must be reestablished.

may be necessary to encourage dispersed flow and prevent concentrated flow.

5. A portion of the riparian forest immediately adjacent to the stream should be managed to maintain a stable streamside ecosystem and to provide detritus and large stable debris to the stream.
6. Crown cover should be managed to minimize fluctuations in stream temperature and to maintain stream temperatures within the range necessary for instream aquatic habitat.
7. Instream slash and debris removal practices should be revised to conserve existing large stable debris by retaining useful stable portions of jams whenever possible. Unstable tops and smaller debris with potential to form problem jams should be removed a sufficient distance to prevent re-entry during storm events.

The attached specification is an example of an effort by several state, federal and private resource management and research organizations to develop criteria for the establishment of effective forest buffers based on current research findings.

USDA Agricultural Research Service, Tifton, GA

▲ *Riparian forest buffers are most effective when used in conjunction with sound land management systems that include nutrient management and sediment control systems.*

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U.S. GOVERNMENT PRINTING OFFICE: 1992—606-177

Vegetation Selection

Zone 1 & 2 vegetation will consist of native streamside tree species on soils of Hydrologic Groups D and C and native upland tree species on soils of Hydrologic Groups A and B.

Deciduous species are important in Zone 2 due to the production of carbon leachate from leaf litter which drives bacterial processes that remove nitrogen as well as to the sequestering of nutrients in the growth processes. In warmer climates evergreens are also important due to the potential for nutrient uptake during the winter months. In both cases a variety of species is important to meet the habitat needs of insects important to the aquatic food chain.

Zone 3 vegetation should consist of perennial grasses and forbs.

Species recommendations for vegetated buffer areas depend on the geographic location of the buffer. Suggested species lists should be developed in collaboration with appropriate state and federal forestry agencies, the Soil Conservation Service and the Fish and Wildlife Service. Species lists should include trees, shrubs, grasses, legumes, forbs, as well as site preparation techniques. Fertilizer and lime, helpful in establishing buffer vegetation, must be used with caution and are not recommended in Zone 1.

Maintenance Guidelines

General

Buffers must be inspected annually and immediately following severe storms for evidence of sediment deposit, erosion or concentrated flow channels. Prompt corrective action must be taken to stop erosion and restore sheet flow.

The following should be avoided within the buffer areas: excess use of fertilizers, pesticides, or other chemicals, vehicular traffic or excessive pedestrian traffic and removal or disturbance of vegetation and litter inconsistent with erosion control and buffering objectives.

Zone 1 vegetation should remain undisturbed except for removal of individual trees of extremely high value or trees presenting unusual hazards such as potentially blocking culverts.

Zone 2 vegetation, undergrowth, forest floor, duff layer and leaf litter shall remain undisturbed except for periodic cutting of trees to remove sequestered nutrient and to maintain an efficient filter by fostering vigorous growth, and for spot site preparation for regeneration purposes. Controlled burning for site preparation, consistent with good forest management practice could also be used in Zone 2.

Zone 3 vegetation should be mowed and the clippings removed as necessary to remove sequestered nutrient and promote dense growth for optimum soil stabilization. Hay or pasture uses can be made compatible with objectives of Zone 3.

Zone 3 vegetation should be inspected twice annually and remedial measures taken as necessary to maintain vegetation density and remove problem sediment accumulations.

Stable Debris

As Zone 1 reaches 60 years of age, it will begin to produce large stable debris. Large debris, such as logs create small dams which trap and hold detritus for processing by aquatic insects thus adding energy to the stream ecosystem, strengthening the food chain and improving aquatic habitat. Wherever possible, stable debris should be conserved.

Where debris dams must be removed, try to retain useful, stable portions which provide detritus storage.

Deposit removed material a sufficient distance from the stream that it will not be refloated by high water.

Planning Considerations

1. Evaluate the type and quantity of potential pollutants that will be derived from the drainage area.
2. Select species adapted to the zones based on soil and site factors and possible commercial goals such as timber and forage.
3. Plan to establish trees early in the dormant season for maximum viability.
4. Be aware of visual aspects and plan for wildlife habitat improvement, if desired.
5. Consider provisions for mowing and removing vegetation from Zone 3. Controlled grazing may be satisfactory in Zone 3 when the filter area is dry and firm.

SPECIFICATION
RIPARIAN FOREST BUFFER

Definition

An area of trees and other vegetation located in areas adjoining and upgradient from surface water bodies and designed to intercept surface runoff, wastewater, subsurface flow and deeper groundwater flows from upland sources for the purpose of removing or buffering the effects of associated nutrients, sediment, organic matter, pesticides or other pollutants prior to entry into surface waters and groundwater recharge areas.

Scope

This specification establishes the minimally acceptable requirements for the reforestation of open lands and renovation of existing forest to be managed as Riparian Forest Buffers for the purposes stated.

Purpose

To remove nutrients, sediment, animal-derived organic matter, and some pesticides from surface runoff, subsurface flow and near root zone groundwater by deposition, absorption, adsorption, plant uptake, denitrification, and other processes, thereby reducing pollution and protecting surface water and groundwater quality.

Conditions Where Practice Applies

Subsurface nutrient buffering processes, such as denitrification, can take place in the soil wherever carbon energy, bacteria, oxygen, temperature and soil moisture are adequate. Nutrient uptake by plants occurs where the water table is within the root zone. Surficial filtration occurs anywhere surface vegetation and forest litter are adequate.

The riparian forest buffer will be most effective when used as a component of a sound land management system including nutrient management and runoff, sediment and erosion control practices. Use of this practice without other nutrient and runoff, sediment and erosion control practices can result in adverse impacts on buffer vegetation and hydraulics including high maintenance, the need for periodic replanting and the carrying of excess nutrients and sediment through the buffer by concentrated flows.

This practice applies on lands:

1) adjacent to permanent or intermittent streams which occur at the lower edge of upslope cropland, grassland or pasture;
2) at the margins of lakes or ponds which occur at the lower edge of upslope cropland, grassland or pasture;
3) at the margin of any intermittent or permanently flooded, environmentally sensitive, open water wetlands which occur at the lower edge of upslope cropland, grassland or pasture;
4) on karst formations at the margin of sinkholes and other small groundwater recharge areas occurring on cropland, grassland or pasture.

   Note: In high sediment production areas (8-20 in/ 100 yrs.), severe sheet, rill and gully erosion must be brought under control on upslope areas for this practice to function correctly.

Design Criteria

Riparian Forest Buffers

Riparian forest buffers will consist of three distinct zones and be designed to filter surface runoff as sheet flow and downslope subsurface flow which occurs as shallow groundwater. For the purposes of these buffer strips, shallow ground water is defined as saturated conditions which occur near or within the root zone of trees and other woody vegetation and at relatively shallow depths where bacteria, oxygen, and soil temperature contribute to denitrification. Streamside Forest Buffers will be designed to encourage sheet flow and infiltration and impede concentrated flow.

Zone 1

Location

Zone 1 will begin at the top of the stream bank and occupy a strip of land with a fixed width of fifteen feet measured horizontally on a line perpendicular to the streambank.

Purpose

The purpose of Zone 1 is to create a stable ecosystem adjacent to the water's edge, provide soil/water contact area to facilitate nutrient buffering processes, provide shade to moderate and stabilize water temperature encouraging the production of beneficial algal forms and to contribute necessary detritus and large woody debris to the stream ecosystem.

Requirements

Runoff and wastewater to be buffered or filtered by Zone 1 will be limited to sheet flow or subsurface flow only. Concentrated flows must be converted to sheet flow or subsurface flows prior to entering Zone 1. Outflow from subsurface drains must not be allowed to pass through the riparian forest in pipes or tile thus circumventing the treatment processes. Subsurface drain outflow must be converted to sheet flow for treatment by the riparian forest buffer or treated elsewhere in the system prior to entering the surface water.

Dominant vegetation will be composed of a variety of native riparian tree and shrub species and such plantings as necessary for streambank stabilization during the establishment period. A mix of species will provide the prolonged stable leaf fall and variety of leaves necessary to meet the energy and pupation needs of aquatic insects.

Large overmature trees are valued for their detritus and large woody debris contributions to the stream ecosystem. Therefore, management of Zone 1 will be limited to bank stabilization and removal of potential problem vegetation. Occasional removal of extreme high value trees may be permitted where water quality values are not compromised. Logging and other overland equipment shall be excluded except for streamcrossings and stabilization work.

Livestock will be excluded from Zone 1 except for designed stream crossings.

Zone 2

Location

Zone 2 will begin at the edge of Zone 1 and occupy an additional strip of land with a minimum width of 60 feet measured horizontally in the direction of flow. Total minimum width of Zones 1 & 2 is therefore 75 feet. Note that this is the minimum width of Zone 2 and that the width of Zone 2 may have to be increased as described in the section "Determining the Total Width of Buffer" to create a greater combined width for Zones 1 & 2.

Purpose

The purpose of Zone 2 is to provide necessary contact time and carbon energy source for buffering processes to take place and to provide for long term sequestering of nutrients in the form of forest trees. Outflow from subsurface drains must not be allowed to pass through the riparian forest in pipe or tile thus circumventing the treatment processes. Subsurface drain out flow must be converted to sheet flow for treatment by the riparian forest buffer or treated elsewhere in the system prior to entering the surface water.

Requirements

Runoff and wastewater to be buffered or filtered by Zone 2 will be limited to sheet flow or subsurface flow only. Concentrated flows must be converted to sheet flow or subsurface flows prior to entering Zone 2.

Predominant vegetation will be composed of riparian trees and shrubs suitable to the site, with emphasis on native species and such plantings as necessary to stabilize soil during the establishment period. Nitrogen fixing species should be discouraged where nitrogen removal or buffering is desired. Species suitability information should be developed in consultation with state and federal forestry agencies, Soil Conservation Service, and Fish and Wildlife Service.

Specifications should include periodic harvesting and timber stand improvement (TSI) to maintain vigorous growth and leaf litter replacement and to remove nutrients and pollutants sequestered in the form of wood in tree boles and large branches. Management for wildlife habitat, aesthetics, and timber are not incompatable with riparian forest buffer objectives as long as shade levels and production of leaf litter, detritus and large woody debris are maintained. Appropriate logging equipment recommendations shall be determined in consultation with the state and federal forestry agencies.

Livestock shall be excluded from Zone 2 except for necessary designed stream crossings.

Zone 3

Location

Zone 3 will begin at the outer edge of Zone 2 and have a minimum width of 20 feet. Additional width may be desirable to accommodate land shaping and mowing machinery. Grazed or ungrazed grassland meeting the purpose and requirements stated below may serve as Zone 3.

Purpose

The purpose of Zone 3 is to provide sediment filtering, nutrient uptake and the space necessary to convert concentrated flow to uniform, shallow, sheet flow through the use of techniques such as grading, and shaping, and devices such as diversions, basins and level lip spreaders.

Requirements

Vegetation will be composed of dense grasses and forbs for structure stabilization, sediment control and nutrient uptake. Mowing and removal of clippings is necessary to recycle sequestered nutrients, promote vigorous sod and control weed growth.

Vegetation must be maintained in a vigorous condition. The vegetative growth must be hayed, grazed or otherwise removed from Zone 3. Maintaining vigorous growth of Zone 3 vegetation must take precedence and may not be consistent with wildlife needs.

Zone 3 may be used for controlled intensive grazing when conditions are such that earthen water control structures will not be damaged.

Zone 3 may require periodic reshaping of earth structures, removal or grading of accumulated sediment and reestablishment of vegetation to maintain effectiveness of the riparian buffer.

Determining need for protection

Buffers should be used to protect any body of water which will not be:

treated by routing through a natural or artificial wetland determined to be adequate treatment;

treated by converting the flow to sheet flow and routing it through a forest buffer at a point lower in the watershed.

Determining total width of the buffer

Note that while not specifically addressed, slope and soil permeability are components of the following buffer width criteria.

Each of the following criteria is based on methods developed or used by persons conducting research on riparian forests.

Streamside Buffers

The minimum width of streamside buffer areas can be determined by any of several methods suitable to the geographic area.

1) Based on soil hydrologic groups as shown in the county soil survey report, the width of Zone 2 will be increased to occupy any soils designated as Hydrologic Group D and those soils of Hydrologic Group C which are subject to frequent flooding. If soils of Hydrologic Groups A or B occur adjacent to intermittent or perennial streams, the combined width of Zones 1 & 2 may be limited to the 75 foot minimum.
2) Based on area, the width of Zone 2 should be increased to provide a combined width of Zones 1 & 2 equal to one-third of the slope distance from the stream bank to the top of the pollutant source area. The effect is to create a buffer strip between field and stream which occupies approximately one-third of the source area.
3) Based on the Soil Capability Class of the buffer site as shown in the county soil survey, the width of Zone 2 should be increased to provide a combined width of Zones 1 & 2 as shown below.

Capability Class	Buffer Width
Cap. I, II e/s, V	75'
Cap. III e/s, IV e/s	100'
Cap. VI e/s, VII e/s	150'

Pond and Lake-Side buffer strips

The area of pond or lake-side buffer strips should be at least one-fifth the drainage area of the cropland and pastureland source area. The width of the buffer strip is determined by creating a uniform width buffer of the required area between field and pond. Hydrologic Group and Capability Class methods of determining width remain the same as for streamside buffers. Minimum widths apply in all cases.

Environmentally Sensitive Wetlands

Some wetlands function as nutrient sinks and when they occur in fields or at field margins can be used for renovation of agricultural surface runoff and/or drainage. However, most wetlands adjoining open water are subject to periodic flushing of nutrient-laden sediments and, therefore, require riparian buffers to protect water quality.

Where open water wetlands are roughly ellipsoid in shape, they should receive the same protection as ponds.

Where open water wetlands exist in fields as seeps along hillslopes, buffers should consist of Zones 1, 2 & 3 on sides receiving runoff and Zones 1 & 3 on the remaining sides. Livestock must be excluded from Zones 1 & 2 at all times and controlled in Zone 3. Where Zones 1 & 3 only are used, livestock must be excluded from both zones at all times, but hay removal is desirable in Zone 3.

Urban Riparian Restoration in the Chesapeake Bay Watershed

A Methodology for Progress

PROJECT DESCRIPTION

The Urban Riparian Restoration Project was initiated to assist communities in restoring urban streams. The reasons for urban stream degradation are numerous but are associated with loss of forest cover, poor stormwater management, and lack of population growth planning. The forestry Work Group of the Chesapeake Bay Restoration Effort acquired funding to accomplish the following: 1) select three watershed where available resources, local interest, and known problems exist, 2) identify one subwatershed or stream segment where riparian breakdown exists. This will be accomplished by developing an identification criteria, 3) re-establish vegetation in the previously identified riparian breakdown areas and 4) conduct a training workshop for community planners, tree planting organizations, and others to demonstrate the techniques learned through this effort.

The Virginia Department of Forestry served as the recipient of the funds and main project support. The project participants are the Metropolitan Washington Council of Governments, Fairfax County Park Authority, Prince William County Department of Public Works, U.S. Fish and Wildlife Service, Fairfax Releaf, Northern Virginia Soil and Water Conservation District, and the Maryland Division of Forestry.

This report summarizes our initial work efforts and represents an evolving methodology to accurately assess our valuable riparian resources. The major premise for the identification criteria is that it be widely usable under a variety of conditions. Each subwatershed represents a different set of physical conditions, political subdivisions, and participating partners.

In order to define more fully project direction, the cooperating partners developed a goal statement and five objectives. They are as follows:

GOAL: To improve water quality and habitat in urbanization watershed related to the Chesapeake Bay through management of riparian forests.

OBJECTIVE 1: The restoration and enhancement of vegetation in riparian and adjacent floodplain areas.

OBJECTIVE 2: The restoration and enhancement of terrestrial and aquatic habitats.

OBJECTIVE 3: The restoration, maintenance, and creation of public access and recreation values.

OBJECTIVE 4:	The encouragement of riparian area protection and enhancement through land use planning.
OBJECTIVE 5:	The enhancement and protection of water quality.

RIPARIAN BREAKDOWN IDENTIFICATION CRITERIA

The development of a riparian evaluation criteria list is an integral part of this overall project. Many localities, planning districts and communities have tree planting projects within riparian areas but there are no definitive methods for prioritizing restoration areas. An overarching methodology to maximize limited resources and direct efforts where most needed has been lacking. Our primary emphasis was to construct a system capable of being used within the whole of the Chesapeake Bay Watershed under a variety of physiographic and political situations.

The criteria was initiated using three sets of information. First, the above goals and objectives focused on what this criteria should accomplish. Second, a literature search yielded information on past efforts to provide a stepping stone for the project. Third, the participants' direct involvement in riparian restoration work proved the most valuable by promoting a hands-on, user friendly approach geared to program accomplishment.

The amount of information available necessitated a two level or tiered approach, to the criteria list. From the onset, it became clear that both a Tier I and a Tier II level was necessary. The Tier I list is a general list of criteria to select areas needing restoration. The Tier II macro is designed to further evaluate sites for restoration from the Tier I macro.

Tables I and II show the Tier I and Tier II criteria listings. A simple rating system has been developed to categorize each parameter. A short description follows each parameter from which the user will select a rating of 3, 2, or 1. The "3" represents a "good" score and "1" a poor score. The user will proceed down the Tier I list using any land use data that is available to assess that subwatershed. Tier I & II represents primarily an office procedure followed by a field check with the micro criteria. If additional information is necessary to adequately show which areas need restoration, then a micro criteria evaluation form (Table III) should be completed. This consists of a thorough field inspection. The subwatershed with the <u>lowest</u> score indicates the greatest need of restoration.

PROJECT CASE STUDY – DIFFICULT RUN, FAIRFAX COUNTY, VIRGINIA

A. COMMON PROBLEM ELEMENTS OF URBAN RIPARIAN AREAS

Change is nature's way of maintaining diversity (Smith 1992). Stream dynamics is a source of such change. This can be accepted as a natural good not to be influenced by human intervention. However, in urban riparian areas, there is limited acreage to allow for this constant change that leads to loss of soil and vegetation through flooding and erosion processes. The disturbance caused by frequent flooding allows for establishment by aggressive non-native plant species that inhibit the establishment of preferred native plant species. Flooding often forces the rechannelization of streams to accommodate runoff from increased areas of non-porous surfaces. With increased volumes of drainage waters comes increased loads of nutrients that degrade water quality. It has been demonstrated that riparian forest ecosystems are excellent nutrient sinks and buffer nutrient and contaminant discharges from a variety of land use areas (Lowrance et al. 1984).

B. BACKGROUND

Difficult Run is situated in Fairfax County, Virginia. It is a major tributary of the Potomac River and the Chesapeake Bay drainage basin. Difficult Run has 10 major tributaries draining a diversity of land use.

Characteristics of Difficult Run Watershed

Drainage area - 57.71 sq. mi.
Channel length of main stem - 14.58 mi.
Channel length of tributaries - 172.06 mi.
Elevation at headwater - 450 ft.
Elevation at confluence - 60 ft.
10 subshed runs -
(1) Rocky
(2) Wolf Trap/Old Courthouse
(3) Piney Branch
(4) Rocky Branch
(5) South Fork
(6) Little Difficult
(7) Snake Den/The Glad
(8) Colvin Run
(9) Piney Run
(10) Captain Hickory

See Attachment 1 for map of Difficult Run 10 subsheds.

Land Use - Difficult Run Watershed was chosen as a watershed model for study because it is a critical environmental area undergoing rapid development. Land use in this watershed is constantly changing from forested areas to urban community land use having adverse effects on water quality and other environmental components.

Water Runoff - It is a common practice to divert normal water runoff pathways into storm sewers. Land development produces large impervious surfaces such as roads and parking lots that eliminate the normal percolation of water into the subsoil. As a consequence, greater volumes of stormwater are redirected to the nearest local streams. This combination of events leads to more frequent flooding during storm events than occurred with previous land use. The velocity in these floods is increased due to the increased water volume. Both the increased volume and velocity contribute to erosion of the stream banks and flooding of "unprotected" land areas. Dams caused by fallen trees occur more often, which further impedes flow of instream water increasing flood conditions.

C. EFFECTS OF VEGETATION ON FLUVIAL PROCESSES

There are significant effects exerted by vegetation located on stream banks and in floodplain areas (Hicklin 1984). Select mechanisms of controlling fluvial processes important to this particular project are: flow resistance, bank strength and the formation of log jams within a stream.

The Virginia Department of Forestry periodically makes an assessment of changes in forest cover in the state. It was found that timberland in Fairfax County decreased from 99,337 acres in 1986 to 92,614 acres in 1992; a 6.8% decrease of which urban development accounted for 85% (Hawkins 1993).

With the loss of forest cover there is a reduction in the control of flood waters by a decrease in flow resistance. Bank strength decreases with a loss of plant root systems to retain soil. Additionally the loss of trees along stream banks decreases the instream habitat quality because of reduction in temperature control and a lack of pooled areas for fisheries (Forest Log. 1993). Other sources of degradation are overgrazing by wildlife and encroachments by local residents. These sources of degradation have been observed in Difficult Run watershed during field surveys.

D. PROJECT OBJECTIVES

Objective I

Determine the extent to which the riparian area and adjacent floodplain of a select section of the Difficult Run mainstem has undergone a loss of vegetation that would result in dissipation of the aforementioned control of fluvial processes.

Objective II

Choose priority sites within the mainstem of Difficult Run for restoration of riparian vegetation.

Objective III

Devise a plan for the planting of appropriate vegetation in selected priority areas of Difficult Run mainstem.

E. IMPLEMENTATION OF OBJECTIVES

Objective I

To determine the extent to which the riparian area and adjacent floodplain of a section of the Difficult Run mainstem has undergone a loss of vegetation, a vegetation inventory has been compiled. The tract selected for the inventory is the mainstem area of Difficult Run starting at Rt. 7 west of the property line of the stream valley park. The area is the acreage on the South side of the stream. Restoration of this area would complete the restoration/enhancement project started in 1992 for this mainstem section of Difficult Run.

The inventory was completed October 1993.

* See Attachment 2 for area of inventory
* See Appendix A for inventory results

Objective II

The criteria and prototype developed by the Urban Riparian Restoration Committee sponsored by the Virginia Department of Forestry was used to prioritize sites for restoration of the Difficult Run mainstem. Sources of decision making information were:

Fairfax County Land Use and Tax Maps
Fairfax County Soil Maps and Descriptions
Fairfax County Contour Maps
A Field Survey of Stream Conditions

The evaluation process was completed December 1993.

* See Attachment 3 for map of sections prioritized for restoration.
* See Appendix B for Criteria and detailed results of prioritization.

Objective III

Fairfax Releaf will use information from the vegetation inventory, prioritization study and recommendations of the Fairfax County Park Authority, to determine species of plans to be used in restoration. Clewell and Lea (1990) suggest observation of surrounding plant communities as a first step in deciding the species to be established. Fairfax Releaf will also consult with the Park Authority on the density and location of plants to be planted within prioritized areas. Funding for the planting of this project is being provided by a grant from the Virginia Department of Forestry.

The planting of this project occurred in Spring 1994 under the supervision of Fairfax Releaf and Fairfax County Park Authority, and the Virginia Department of Forestry.

F. RESULTS

There were seven sites evaluated, each approximately 250,000 sq.ft. Five of the seven sites of the Difficult Run mainstem considered were indicated to be in need of restoration (NOR); two sites have acceptable riparian vegetation cover (ACC). The ratings of the sites were as follows:

Plot	# 1 = 1.76	NOR
	# 2 = 2.00	ACC
	# 3 = 1.70	NOR
	# 4 = 1.75	NOR
	# 5 = 1.93	NOR
	# 6 = 2.00	ACC
	# 7 = 1.90	NOR

The prioritization rankings for restoration would be as follows: Plots 3, 4, 1, 7 and 5. Plots 2 and 6 currently have acceptable conditions.

The planting of the prioritized sites on the mainstem of Difficult Run took place in Spring 1994. A list of the seedlings planted can be found in Attachment 4. A map illustrating the planting sites can be found in Attachment 5.

It is anticipated that other sites on tributaries of Difficult Run will be evaluated and slated for restoration according to the need established.

The results expected from this project are:

* An improvement of habitat quality for the restored areas.
* A decrease in flash flooding in the restored area of Difficult Run mainstem.
* A decrease in non-point source pollutants entering Difficult Run.

REFERENCES

Clewell, Andrew F. and Russ Lea. 1990. Creation and restoration of forested wetland vegetation in the Southeastern United States. In: Wetland Creation and Restoration: The Status of the Science. Washington, D.C.: Island Press. Pages 195-232.

DCR, Department of Conservation and Recreation. 1993. Virginia: Nonpoint Source Pollution Watershead Assessment Report, Richmond, VA. March.

Hawkin, Keith. 1993. Forest Loss is Local Trend, Community Forester, Virginia Department of Forestry. January.

Hickin, Edward J. 1984. Vegetation and River Channel Dynamics. Canadian Geographer 28 (2).

Lowrance, Richard, R. Todd, J. Fail, Jr., O. Hendrickson, Jr., R. Leonard, Loris Asmussen. 1984. Riparian Forests as Nutrient Filters in Agricultural Watersheds. BioScience 34 (6).

Smith, Robert L. 1992. <u>Elements of Ecology third edition.</u> Harper Collins Publishers, New York.

Locating Sites

Materials Needed →

Tax Maps – Property ownership

U.S.G.S. Quads
streams < blue line
intermittant
roads

soils Maps

Aerial Photos

NWI – Wetlands Maps

URBAN RIPARIAN RESTORATION PROJECT

TIER I MACRO CRITERIA

Tier I criteria are used to determine if an individual site warrants further evaluation until *Micro Criteria* are evaluated. If a site scores in the *Fair* range or below on Tier I Macro Criteria, then proceed to Tier II Macro Criteria for further site evaluation.

Tier I	Criteria	Description	Rating	Score
I	Cover Type/ Density	Sufficient vegetative cover to retain soil	3	
		Sufficient vegetation to minimize soil loss	2	
		Low level of vegetative cover - erosion in progress	1	
I	Buffer Width	>150 feet of good transitional vegetation on both sides of stream	3	
		50 - 150 feet of transitional vegetation on both sides of stream	2	
		50 feet of transitional vegetation on both sides of stream	1	
I	Slope of Adjacent Land	<10% Slope	3	
		10 - 15% Slope	2	
		>15% Slope	1	
I	Landownership	Private land bordering both sides of stream	3	
		Private land and public land bordering both sides stream	2	
		Public land ownership on both sides of stream	1	
	SUB-TOTAL SCORE			

Score Ranges:

9 - 12 = *Good*
6 - 8 = *Fair (proceed to Tier II if the score is in or below Fair Range)*
Less than 5 = *Poor*

Site Information

Site Name:____________________

Date:____________________

Location/Coordinates:____________________

Stream Segment:____________________

Evaluators Name:____________________

URBAN RIPARIAN RESTORATION PROJECT TABLE II

TIER II MACRO CRITERIA

Tier	Criteria	Description	Rating	Score
II	*Continuity	Cover type continuous	3	
		Some interruption of cover type	2	
		Extremely fragmented cover type	1	
II	*Contiguity	> 10 acres of contiguous non-riparian homogeneous land	3	
		6 - 9 acres of contiguous non-riparian homogeneous land	2	
		< 5 acres of contiguous non-riparian homogeneous land	1	
II	Adjacent Land Use	Developed public land adjoining area	3	
		Developed medium-density, residential, commercial or industrial area	2	
		Pasture/crop agricultural, golf courses or high density residential, commercial or industrial areas	1	
II	Stream Order	>5th order stream	3	
		>3rd and <5th order stream	2	
		<3rd order stream	1	
II	Erodabilty	Erodability constant of < .3	3	
		Erodability constant of .3	2	
		Erodability constant of > .3	1	
II	Endangered Species	No known presence of endangered or threatened species or habitat quality to support those species	3	
		Possibility of the presence of endangered or threatened or species of concern and habitat to support species	2	
		Known presence of species or ecological element of concern with considerable habitat degradation	1	
II	Fisheries	Presence of native fish or habitat quality to support fisheries (pools, shaded areas and passage ways)	3	
		Previously supported fish population with potential habitat to support fisheries	2	
		Potential to support fish population, enhancement required to provide appropriate habitat	1	
II	Sensitive Resources	Presence of a wetland, historical/archeological site, etc.	3	
		Indeterminate presence of sensitive resources	2	
		No sensitive resources present	1	
	TOTAL SCORE			

* *The use of these criteria are determined and defined by the user.*

Score Ranges:

18 - 24 = *Good* (restoration not required)
12 - 17 = *Fair* (restoration potentially useful)
Less than 12 = *Poor* (restoration needed, proceed to **Sheet 3**, Micro Criteria)

Sheet 2

Micro Criteria Part One - Site Level Evaluation Form

Field Check of Selected Tier I and II Macro Criteria

The micro criteria evaluation has two parts: 1) to field check *Tier One* and selected *Tier Two* macro criteria, and 2) to perform a more detailed site restoration feasibility assessment. The same ranking system used in the macro criteria will be used for the micro criteria evaluation. If a criteria evaluation changes after conducting a field check of the macro criteria, then place the new score in the macro criteria form and recalculate the total site score. Prior to site check, enter the Tier I & II results in the space provided for comparison. When completed, proceed to *Part Two Field Check* (Sheet 4).

Tier	Criteria	Initial Description of Site from Tier I & 2 Evaluation	Initial Score	Field Score
I	Cover Type/Density			
	Field Notes:			
I	Forest Buffer Width/Location			
	Field Notes:			
I	Adjacent Land Slope			
	Field Notes:			
II	Continuity			
	Field Notes:			
II	Adjacent Land Use			
	Field Notes:			
II	Erodability			
	Field Notes:			
II	Fisheries			
	Field Notes:			

Additional Field Notes:

URBAN RIPARIAN RESTORATION PROJECT

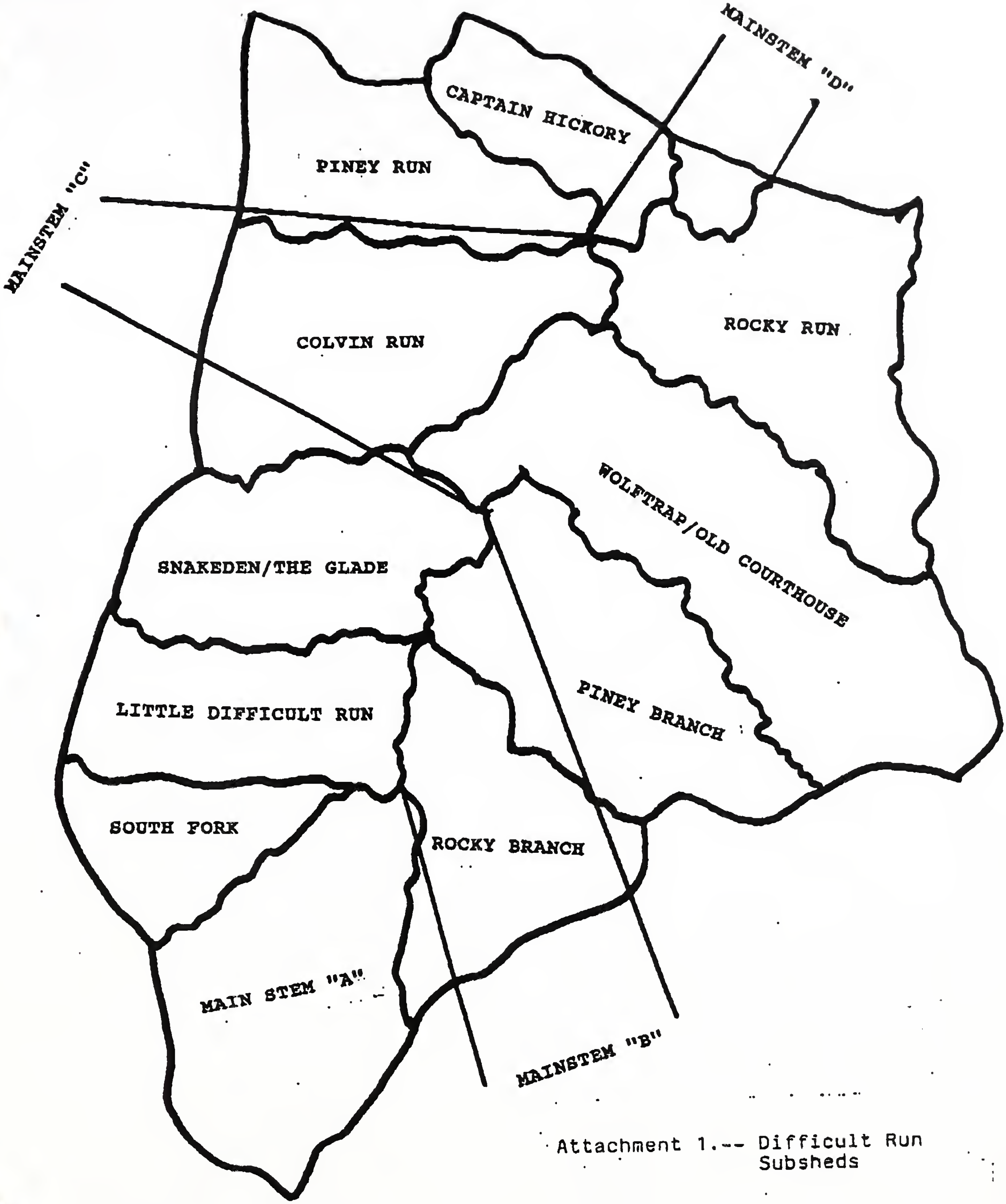
MICRO CRITERIA - PART TWO SITE RESTORATION FEASIBILITY

Criteria	Indicator	Ranking	Score
PHYSICAL STRUCTURE OF THE STREAM *(Level of Streambank Erosion)*			
Bank failure (erosion)	Severe	3	
	Moderate	2	
	Minimum/normal	1	
Lack of stable streambank vegetation near water level	Severe	3	
	Moderate	2	
	Minimum/normal	1	
Frequency of tree falls into stream	Severe	3	
	Moderate	2	
	Minimum/normal	1	
Frequency of exposed root-mat along streambank	Severe	3	
	Moderate	2	
	Minimum/normal	1	
Channel Armoring *(Concrete, rip-rap, gabion or other streambank stabilizing materials)*	Three sided (no natural channel)	3	
	1 or 2 sided	2	
	Not Present	1	
OTHER USES			
Recreational Use*	Intense (Ballfields)	3	
	Moderately Intense (Hiker/Biker trails)	2	
	Low Intensity (unplanned/unmanaged use)	1	
Other Use			
SPECIAL CONCERNS**			
Stream Hydrology: *(Frequency of Overbank Flows)*	Standing water within project area	yes or no	
	Silt covered leaves within project area	yes or no	
	Water-borne debris within project area	yes or no	
Future Stormwater Management Projects	*See Text*	yes or no	
Soil Planting Quality	Hardpan, heavy clay, sandy, hydric, etc.	yes or no	
Animal Damage	Deer Browse, Beaver, Livestock	yes or no	
Other Concerns			

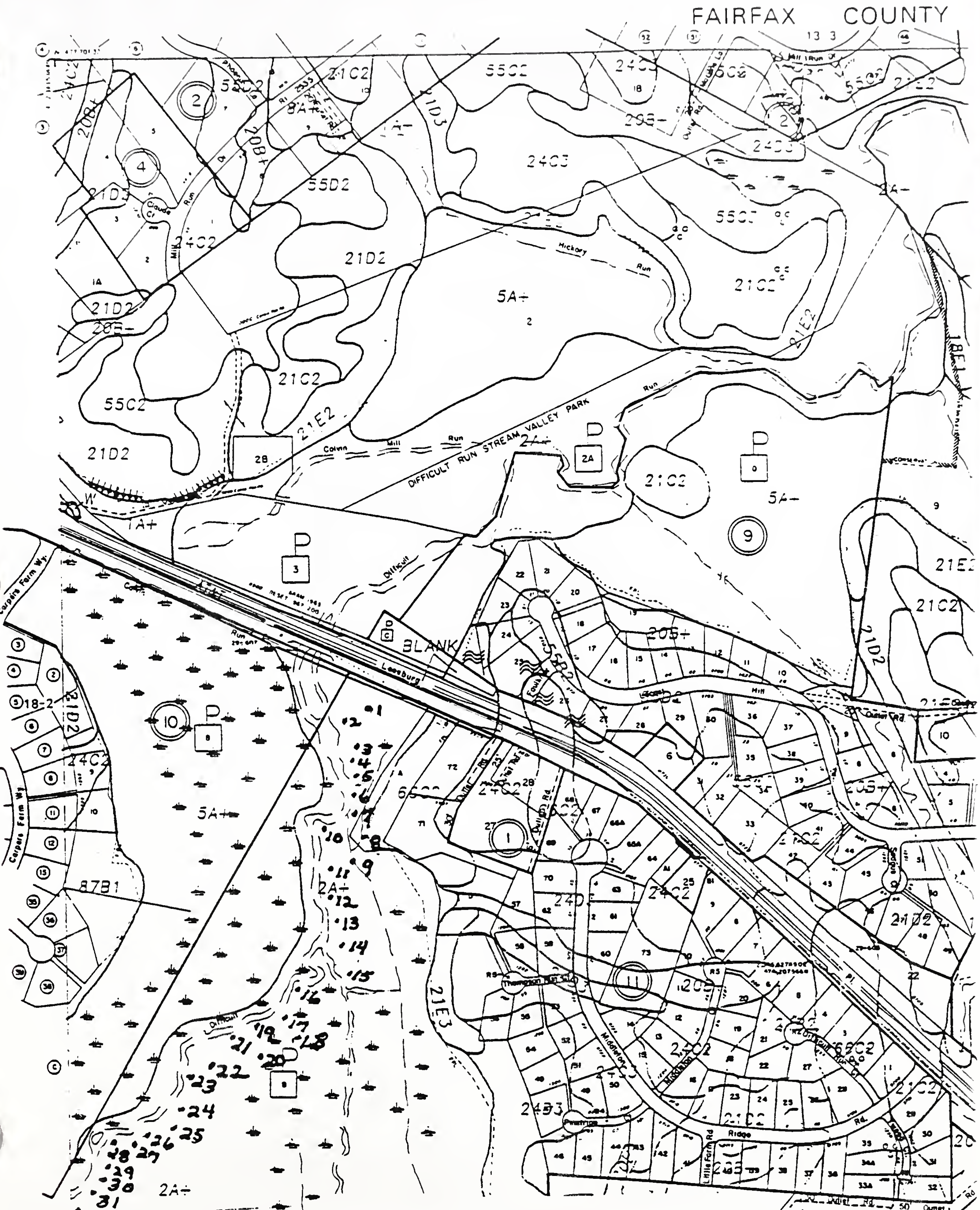
* For recording on-site or adjacent recreational uses that may impact the targeted restoration area.

**Any of these *may* be justification to eliminate a particular site from restoration activities.

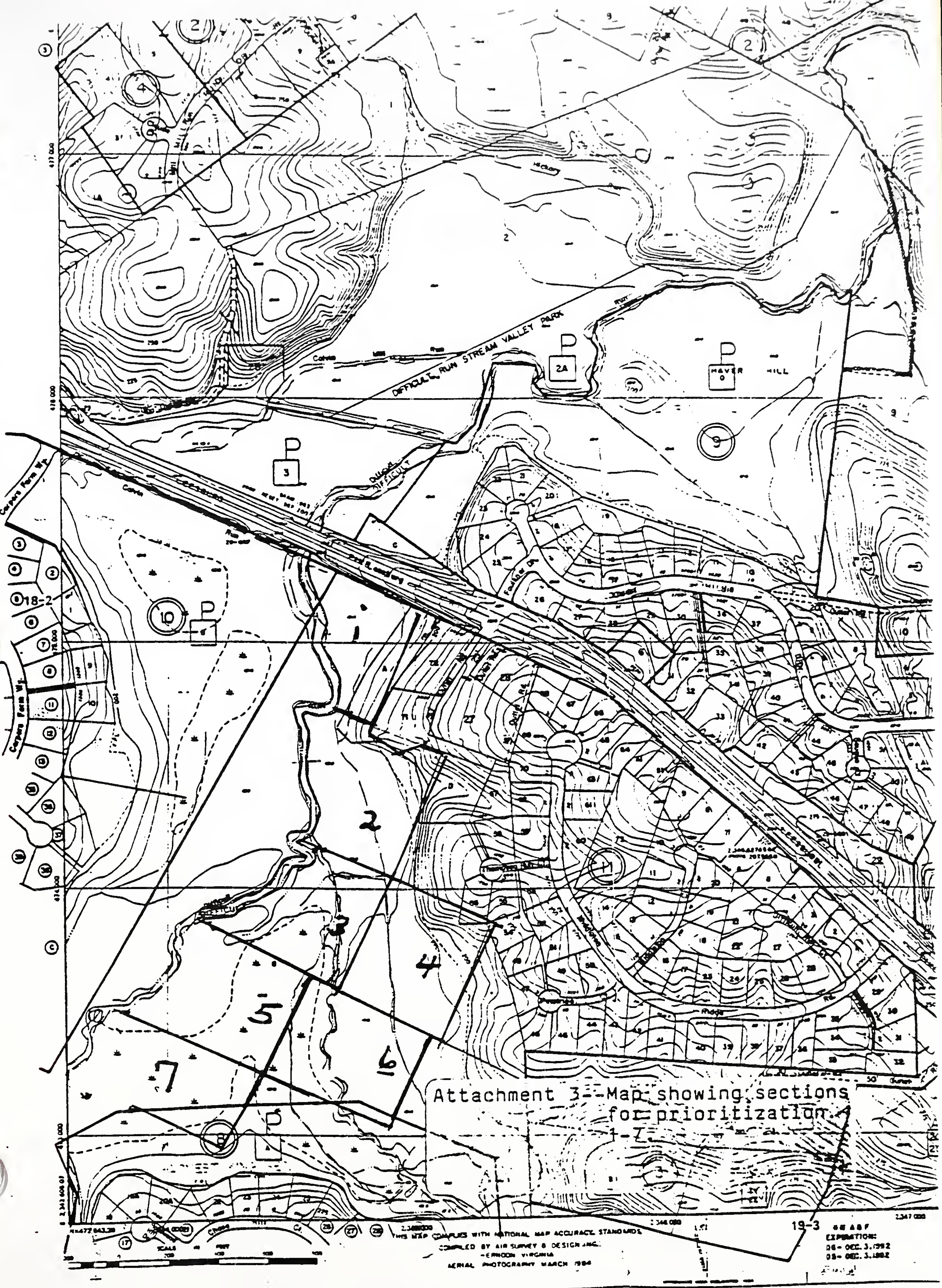
Note: *Opportunities may exist to include restoration areas in other planned projects for that area. However, this may also be justification to eliminate a restoration if the planned projects are incompatible with the restoration.*



Attachment 1.-- Difficult Run Subsheds



Attachment 2-- Area of Inventory
with quadrats
1-33 marked.

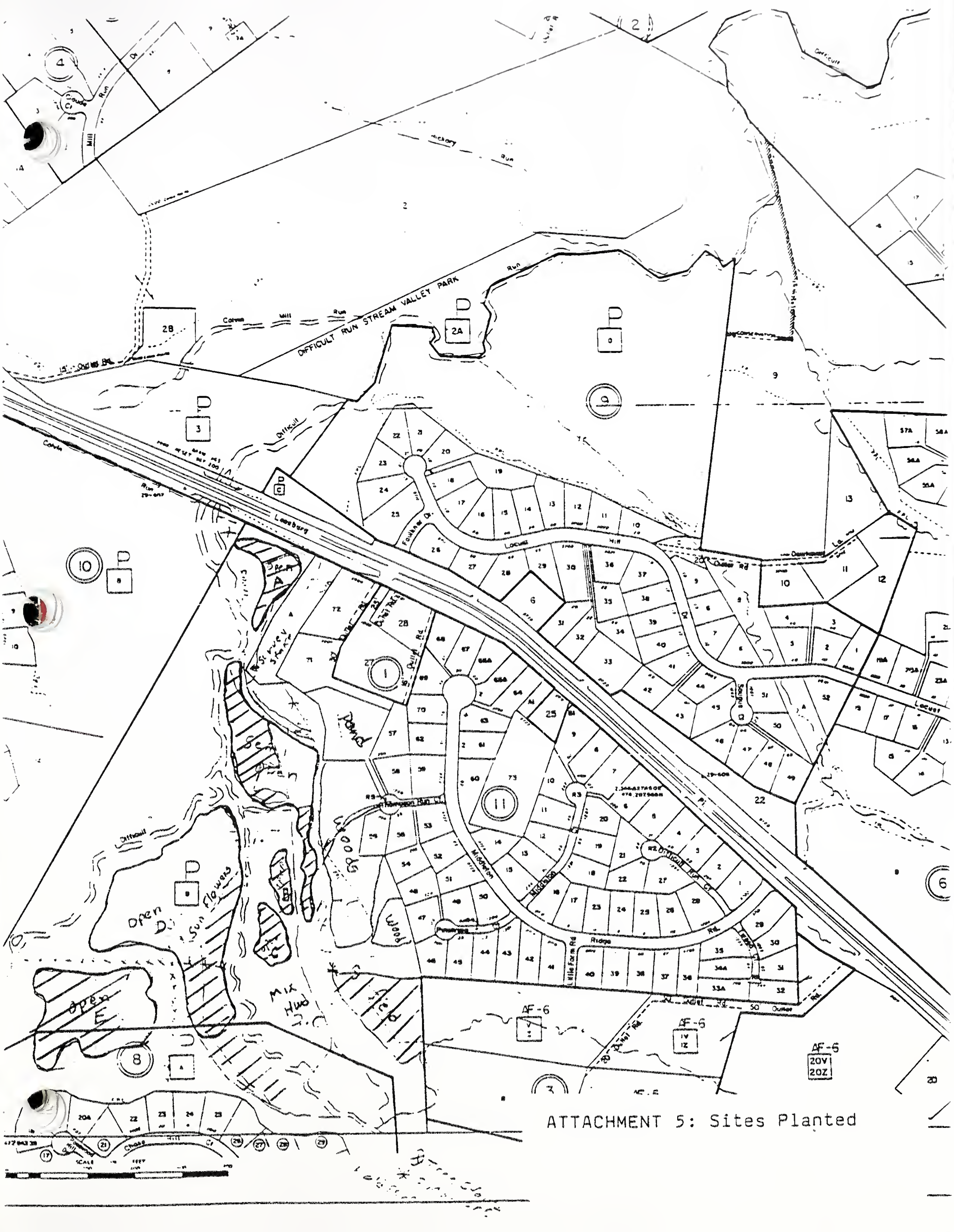


Attachment 3 - Map showing sections for prioritization 1-7

Planted Species and Distribution for Difficult Run, April 18, 1994

OPEN A:	Common apple	15	
	Virginia pine	110	
	Sweetgum	35	
	River birch	50	
	Walnut	10	
	Southern red oak	37	
	White oak	27	
	Yellow-poplar	50	334
SEMIOPEN:	Common apple	15	
	Virginia pine	150	
	Sweetgum	165	
	Southern red oak	148	
	River birch	150	
	Gray dogwood	100	
	White oak	156	
	Persimmon	20	904
OPEN B:	Sycamore	25	
	Pin oak	28	
	Virginia pine	50	
	Yellow-poplar	25	128
OPEN C:	Green ash	100	
	Yellow-poplar	125	
	Willow oak	25	
	Persimmon	10	260
OPEN D:	Water oak	300	
	Sycamore	100	
	Green ash	200	600
OPEN E:	Yellow-poplar	50	
	Willow oak	53	
	Water oak	50	
	Sycamore	50	
	Red maple	83	
	Green ash	300	586
FIELD:	Virginia pine	50	
	Common apple	20	
	White oak	297	
	Yellow-poplar	100	
	Southern red oak	216	
	Walnut	40	
	Persimmon	20	743
			3555

ATTACHMENT 4: List of Plants



ATTACHMENT 5: Sites Planted

APPENDIX B

PRIORITIZATION RESULTS

EVALUATION OF DIFFICULT RUN MAINSTEM

PLOT	CRITERIA	ATTRIBUTES	RATING
# 1	Covertype	Old Field/ Floodplain Forest High sp. richness	2.5
	Density	Sufficient Cover	2.0
	Continuity	Some Fragmentation	2.0
	Contiguity	Not contiguous	1.0
	Landownership	Public	3.0
	Adjacent Land Use	Buffered Residential	2.0
	Recreational Use	Public access No trails	1.5
	Buffer	>150 ft.	2.5
	Stream Order	>5	1.0
	Stream hydrology	flashy hydrology	1.0
	Physical Struct. in Stream	Partially stable	2.0
	Slope	<10%	3.0
	Erodability	K=.37	1.0
	Sensitive Resources	Species of Concern (Deer)	1.0
	Fisheries	Potential to support fisheries enhancement needed	1.0
Total			26.5 / 15
Rating			1.76

Site Description:
Plot # 1 is comprised of inventory quadarats 1-6 having a major Old Field covertype. There is a total of 44 trees/saplings in this plot with ages between 10-20 years. The total plant species for this area is 64, indicating good diversity. The soil type for this area is Glenelg Silt Loam. The stream bordering this plot has a bank height of 2-3 ft.

There is moderate damming with moderate undercutting.

PLOT	CRITERIA	ATTRIBUTES	RATING
# 2	Covertype	Old Field Mod. Sp. richness	2.0
	Density	Mod. to Low cover	1.5
	Continuity	Some fragmentation	2.0
	Contiguity	Intermittent stands of trees with transitional vegetation	2.0
	Landownership	Public	3.0
	Adjacent Land Use	Buffered open space	3.0
	Recreational	No public access	1.0
	Buffer	> 150 ft.	3.0
	Stream Order	> 5	1.0
	Stream hydrology	Flashy	1.0
	Physical Structure in stream	Severe silting and bedloading	1.0
	Slope	< 10 %	3.0
	Erodability	K=< .3 but considerable erosion is taking place	2.5
-	Sensitive species	Species of concern Deer and Geese	1.0
	Fisheries	Potential fisheries habitat due to damming	2.0
Total			30 15
Rating			2.0

Site Description:
Plot # 2 is comprised of inventory quadrats 7-13. It has a covertype of Old Field and some Flood Plain Forest. There are 31 trees/ saplings in this area with ages to 20 years. A total of 42 different plant species were recorded. The soil type in this area is Chewacla silt loam. The stream banks are 4-6 ft. high, with moderate damming and undercutting.

PLOT	CRITERIA	ATTRIBUTES	RATING
# 3	Covertype	Old Field Sparse to Barren	1.5
	Density	Sparse Cover Erosion in progress	1.0
	Continuity	Fragmented Habitat	1.0
	Contiguity	Intermittent stands of trees, difficult to move through this area	1.0
	Landownership	Public	3.0
	Adjacent Land Use	Open Space	3.0
	Recreational Use	No access	1.0
	Buffer	> 150 ft.	3.0
	Stream order	> 5	1.0
	Stream hydrology	flashy hydrology	1.0
	Physical Struc. in Stream	Moderate silting and bedloading	2.0
	Slope	< 10 %	3.0
	Erodability	K= .37	2.5
	Sensitive Resources	Species of concern Deer	1.0
	Fisheries	Dammed and pooled areas	1.0
Total			26/15
Rating			1.7

Site Description:
Plot # 3 is comprised of inventory quadrats 14-20 with a covertype of Old Field. There are 15 trees/saplings in this area with ages between 1- 8 years old. There are 35 different plant species recorded. The soil type is Meadowville Silt Loam. The stream conditions at this site show moderate to severe undercutting and damming. Wolftrap Run, a Difficult Run tributary, flows through this plot.

PLOT	CRITERIA	ATTRIBUTES	RATING
# 4	Covertype	Old Field Wet Meadow	2.0
	Density	N/A	0
	Continuity	Mixed covertype	1.5
	Contiguity	Essentially no trees Tall herbaceous cover	1.5
	Landownership	Public	3.0
	Adjacent Land Use	Residential Slight Buffer	1.5
	Recreational Use	No access	1.0
	Buffer	< 50 ft	1.0
	Stream Order	N/A	0
	Stream hydrology	N/A	0
	Physical Struct. in Stream	N/A	0
	Slope	10%	2.0
	Erodability	K= .37	2.5
	Sensitive Resources	Wet Meadow	1.5
	Fisheries	N/A	0
Total			17.5 / 10

Rating 1.75

Site Description:
Plot # 4 is not within the area inventoried. The covertype is Old Field/ Wet Meadow. The plot is 100 ft. from Wolftrap Run tributary to Difficult Run and approximately 500 ft. from Difficult Run. The soil type is Meadowville Silt Loam.

PLOT	CRITERIA	ATTRIBUTES	RATING
# 5	Covertype	Old Field/ Flood Plain Forest Wet Meadow	2.0
	Density	Areas of bare soil erosion evident	1.5
	Continuity	Fragmented habitat	1.5
	Contiguity	Intermittent stands of trees with transitional vegetation	2.0
	Landownership	Public	3.0
	Adjacent Land Use	Buffered Open Space	3.0
	Recreational Use	No Access	1.0
	Buffer	> 150 ft.	3.0
	Stream Order	> 5	1.0
	Stream hydrology	flashy hydrology	1.0
	Physical Struct. in Stream	Considerable damming moderate silting	2.0
	Slope	< 10 %	3.0
	Erodability	K= .32	2.5
	Sensitive Resources	In stream amphibians	0.5
	Fisheries	Some pools enhancement required	1.0
Total			29 / 15
Rating			1.93

Site Description:
Plot # 5 is comprised of inventory quadrats 21-27. The covertype is Old Field/ Floodplain Forest. There are 13 trees in this area aging between sapling to 20 years. The total different plant species recorded for this area is 44. The soil type is Wehadkee Silt Loam. The stream bank in this area is 4-5 ft. in height with moderate undercutting and severe damming.

PLOT	CRITERIA	ATTRIBUTES	RATING
# 6	Covertype	Wet Meadow/ Flood Plain with some trees	2.5
	Density	N/A	0
	Continuity	Intermittent cover	1.5
	Contiguity	Fragmented cover	1.5
	Landownership	Public	3.0
	Adjacent Land Use	Buffered Residential	2.0
	Recreational Use	No access	1.0
	Buffer	> 150 ft.	3.0
	Stream Order	1-2 order Wolftrap Run cuts through this area	3.0
	Stream hydrology	N/A	0
	Physical Struct. In Stream	N/A	0
	Slope	10%	2.5
	Erodability	K= .43	1.0
	Sensitive Resources	Wet Meadow	1.0
	Fisheries	N/A	0
Total			22/11
Rating			2.0

Site Description:
Plot # 6 is not in the inventoried area. The covertype indicated by aerial photo is mainly Wet Meadow. The soil type is Manor Silt Loam. Wolftrap Run a Difficult Run tributary diagonally through the center of this plot.

PLOT	CRITERIA	ATTRIBUTES	RATING
# 7	Covertype	Flood Plain Forest Wet Meadow	2.5
	Density	Sufficient vegetation to check soil erosion	2.0
	Continuity	Mixed intermittent cover	2.0
	Contiguity	Mixed intermittent cover some corridor	2.0
	Landownership	Public	3.0
	Adjacent Land Use	Open Space Public Land	3.0
	Recreational Use	No access	1.0
	Buffer	< 50 Ft. in one area	1.0
	Stream Order	> 5	1.0
	Stream hydrology	Flasny hydrology	1.0
	Physical Struc. in Stream	Moderate damming	2.0
	Slope	< 10 %	3.0
	Erodability	K= .32	2.5
	Sensitive Resources	Wet Meadow Beaver & Deer activity	1.5
	Fisheries	Pooled areas for potential fisheries	1.0
Total			28.5 / 15
Rating			1.9

Site Description:
Plot # 7 is comprised of inventory quadrats 28-33. The covertype of this area is Floodplain Forest/ Wet Meadow. There were 14 trees recorded in this area between the ages of seedlings and 10 yrs. There are 36 different plant species recorded from these 5 quadrats. The area controlled by invasive species is extensive. The soil type is Wehadkee Silt Loam. The stream in this area has a bank height of approximately 5 ft. Damming and undercutting is moderate.

Chesapeake Bay Commission

RESOLUTION

A legislative commission serving Maryland, Pennsylvania and Virginia.

Resolution Supporting the Development of a Riparian Forest Buffer Policy Adopted by the Chesapeake Bay Commission June 9, 1994

WHEREAS, in 1987, the signatories to the Chesapeake Bay Agreement committed to achieving by the year 2000 a 40 percent reduction of nitrogen and phosphorus reaching the main stem of the Chesapeake Bay, and

WHEREAS, the tributaries of the Chesapeake Bay provide essential habitat for the health and propagation of the Bay's living resources, and there is a demonstrated link between water quality and the survival and health of those resources, and

WHEREAS, the 1992 amendments to the Chesapeake Bay Agreement commit the signatories to develop and begin implementation of tributary-specific strategies that will meet mainstem nutrient reduction goals and achieve water quality requirements necessary to restore living resources in both the mainstem and the tributaries of Chesapeake Bay, and

WHEREAS, in 1993, the signatories to the Chesapeake Bay Agreement outlined their commitment to the restoration of historic habitats for migratory fish species through the construction of fish passages, and

WHEREAS, the survival and propagation of migratory fish species in their historic habitats is dependent upon not only passage to those areas but also the achievement and maintenance of the physical, chemical, and biological integrity of the water resource necessary to support living resource habitats, and

WHEREAS, the ability of forests to absorb and denitrify nitrogen in surface and groundwater and to trap phosphorus-laden sediment from adjacent land uses has been documented to result in the lowest level of nutrient loading of any land use, and

WHEREAS, in addition to nutrient reduction, riparian forests, through the provision of shade, organic detritus, and root structure, provide a host of living resource habitat benefits, including the moderation of stream temperature, support of the food web, sediment and erosion control, creation of fish habitat, and the maintenance of stream morphology and hydrologic structure, and

WHEREAS, the Forestry Work Group of the Chesapeake Bay Program has recognized the enormous value of streamside forests in providing quality aquatic habitat, enhancement of living resources of the Bay, and the important role that forest buffers play in achieving greater control over nonpoint-source pollutants reaching the Chesapeake Bay and its tributary rivers and streams, and

WHEREAS, only 60% of the Chesapeake Bay region's historic forest cover now remains, and

WHEREAS, the majority of the estimated 100,000 miles of rivers and streams in the Chesapeake Bay watershed are comprised of smaller streams, where the interaction between the aquatic and terrestrial environments, and thus the impact on water quality, is the greatest, and

WHEREAS, riparian forest buffers deliver the greatest range of environmental benefits of any type of stream buffer, and that maintenance and restoration of riparian forests, when possible, is the preferred method of stream protection, and

WHEREAS, much remains to be learned about the inventory and condition of remaining riparian forests in the watershed, and

WHEREAS, much has been done by state and federal agencies, private landowners, and industry to improve the quality of our aquatic resources through the protection of riparian forests and other stream protection efforts, yet no policies to better coordinate these efforts have been adopted by the Chesapeake Bay Program, and

WHEREAS, the Chesapeake Bay Program, because of its broad-based policy orientation and scientific expertise, is best suited to garner consensus on a comprehensive, Baywide riparian forest policy,

NOW, THEREFORE, BE IT RESOLVED, it shall be the policy of the Chesapeake Bay Commission to work, where possible, to maintain riparian forests where they exist and restore them where they have been lost, and .

BE IT FURTHER RESOLVED, that the Chesapeake Bay Commission recognizes the importance of the role of riparian forests in the protection of water quality and the restoration of the Chesapeake Bay and its tributaries, and

BE IT FURTHER RESOLVED, that the Chesapeake Bay Commission urges the Chesapeake Bay Program to develop a riparian forest policy that strives to maintain riparian forests where they exist and restore them where they have been lost, to be considered for adoption by the Executive Council, to help direct and coordinate the work of the subcommittees and the budget process, and

BE IT FURTHER RESOLVED, that the Chesapeake Bay Commission urges the broadest possible public participation in the development and implementation of a riparian forest policy, and will strongly support involvement by landowners, federal, state and local governments, non-profit organizations, business, industry, scientists, and citizens, and

BE IT FURTHER RESOLVED, that a Chesapeake Bay Program riparian forest buffer policy should consider:

1. A commitment to maintenance, restoration, and stewardship of the resource;

2. An accepted definition of a forest buffer which addresses buffer characteristics, such as width, density, and species composition, buffer functions, such as nutrient reduction and provision of habitat, and resource management activities appropriate within the riparian zone;

3. The implementation of a watershed-wide inventory of riparian forests, so that the extent and condition of riparian areas without adequate forest buffers can be known;

4. A review of existing riparian protection and restoration regulations, programs, and policies within the watershed, to ascertain what impact on riparian forests may be expected from their application and to identify gaps in satisfying restoration or protection needs;

5. The identification of elements of other state and federal programs that either promote or discourage the maintenance and restoration of riparian forests;

6. The identification of incentives or disincentives to landowners and local governments to maintain and restore riparian forests;

7. Based on the accepted definition, inventory, and review of current programs and practices, a quantifiable goal, measured in acres or stream miles, which serves as a long-term target for the maintenance and restoration of riparian forests, as well as a timetable for the achievement of this goal;

8. Resource management strategies within riparian zones that accommodate the needs of people with the need to maintain adequate buffer functions for the protection of water quality and living resource habitats;

9. The relationship of the policy to the tributary strategies and fish passage goals of the Chesapeake Bay Program;

10. Methods to target riparian forest research to the goals of the Chesapeake Bay Program, including monitoring water quality in riparian areas;

11. Coordinated, team-oriented approaches among state agencies, local governments, non-profit organizations, the private sector, and citizens that reach out to riparian land owners and land managers, and

BE IT FURTHER RESOLVED, that a forest buffer policy should recognize that not all landowners or land managers will be able to implement riparian forest buffers, and therefore other stream protection measures should be supported through cooperative efforts, and

BE IT FINALLY RESOLVED, that the Chesapeake Bay Commission commits to examining existing state and federal programs, policies, and regulations to determine their effectiveness in promoting the maintenance and restoration of riparian forests.

VA DEPARTMENT OF FORESTRY GRANT PROGRAMS

SMALL BUSINESS ADMINISTRATION NATURAL RESOURCES DEVELOPMENT PROGRAM

Purpose: Tree planting using "small business" contractors

URBAN and COMMUNITY FORESTRY ASSISTANCE GRANTS

Purpose: Program development, non-profit organization start-up, demonstration areas, research projects, information/education material development, staffing for government and non-profit organizations

SMALL BUSINESS ADMINISTRATION GRANTS

1. Federal funds may only be used for procurement, site preparation, planting, and establishment of **trees.**

2. Funds are awarded on a **matching** basis. The federal share will not exceed **55%**.

3. Matching can be with other funding or "in-kind" which can include volunteer hours, donated materials or services.

4. Small businesses must be used on the project. The use of as many small businesses as possible is encouraged.

5. Projects must have a **3-year maintenance schedule**.

6. Records of maintenance must be kept for 3 years.

7. SBA grants are reimbursement grants paid after verification of project completion and matching funds or "in kind" materials or services.

OBJECTIVES OF THE SMALL BUSINESS ADMINISTRATION GRANT PROGRAM

Projects must meet one or more of the following objectives:

timber production
watershed protection
air quality improvement
energy conservation
beautification
community development
windbreaks
wildlife management
education
screening

KEY DATES FOR SBA GRANTS

REQUEST FOR PROPOSAL PACKETS MAILED OUT ON **NOVEMBER 15**

PROPOSALS DUE TO DEPARTMENT OF FORESTRY BY **FEBRUARY 1**

APPLICANTS SPEND ALLOCATED FUNDS BETWEEN **OCTOBER 1 AND MAY 1**

FINAL REPORT DUE BY **MAY 15**

FUNDING AVAILABLE

Up to **$15,000** per federal ID number

A total of **$431,600** available in the next funding cycle

$200,000 of carryover funds available right now!

URBAN and COMMUNITY FORESTRY ASSISTANCE GRANTS
(AMERICA THE BEAUTIFUL)

1. Funds awarded on a **matching** basis. The federal share will not exceed **50%**

2. Matching can be with other funding or "in kind".

3. U & CF grants are **not** for the purpose of tree planting although some tree planting is allowed.

4. The focus of the program is to fund **new initiatives**.

5. This is generally a **reimbursement** grant, but some non-profit organizations can receive funding up-front.

ELIGIBLE PROPOSALS

Riparian forest management or urban stream restoration

Public education and/or information materials

Development of tree protection ordinances

Training and continuing education

Local government staffing

Non-profit organization staffing

Demonstration Projects

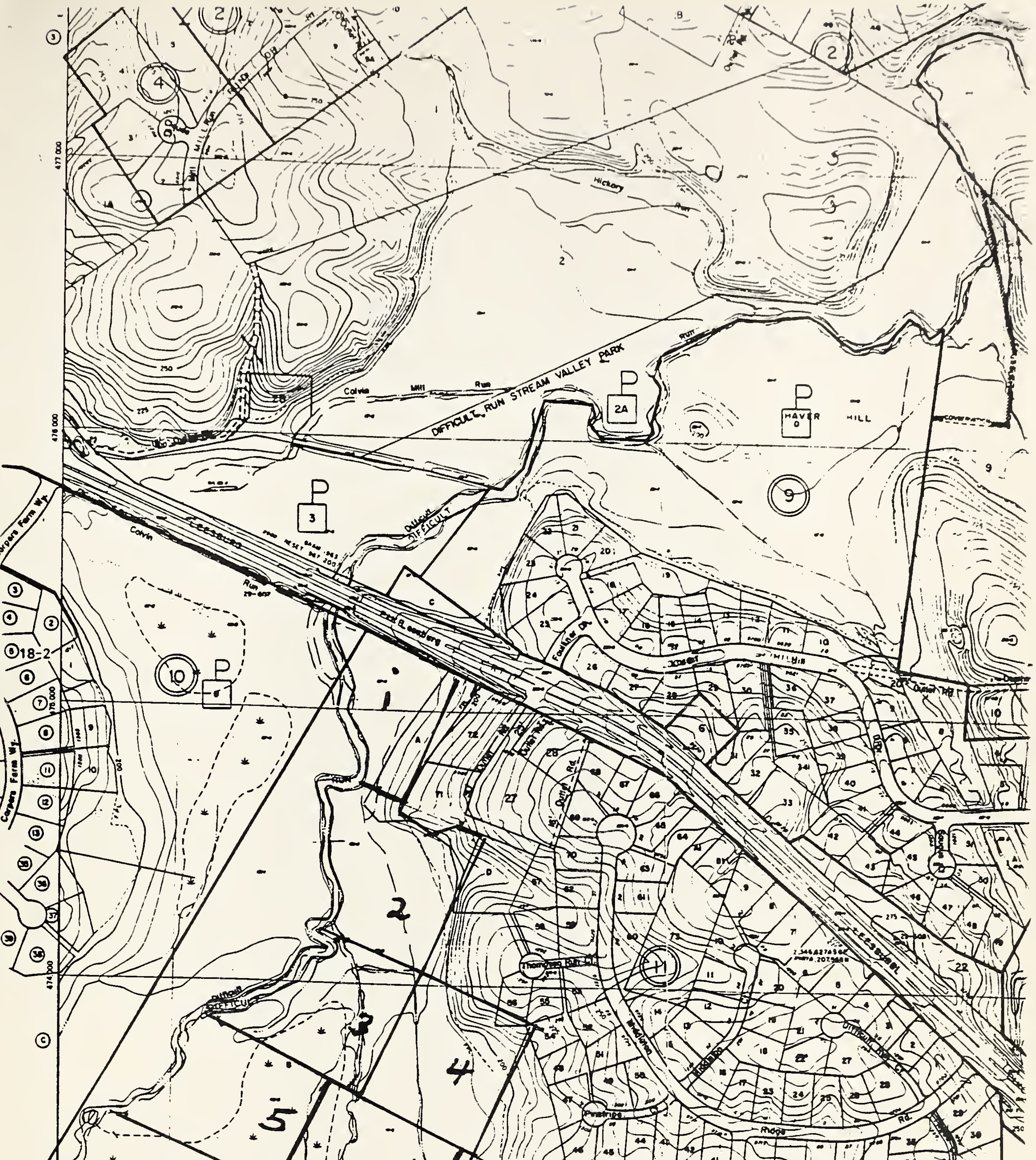
Research Projects

KEY DATES FOR U & CF GRANTS

1. REQUEST FOR PROPOSAL PACKETS MAILED OUT ON **MARCH 1**
2. PROJECT PROPOSALS DUE ON **MAY 15**
3. PROJECT PERIOD RUNS **JULY 15 TO MAY 15**

FUNDING AVAILABLE

1. Up to **$15,000** per federal ID number
2. Total funding usually **$180,000-$200,000**



Attachment 3--Map showing sections for prioritization 1-7.

ATTACHMENT 5: Sites Planted

Planted Species and Distribution for
Difficult Run, April 18, 1994

OPEN A:	Common apple	15	
	Virginia pine	110	
	Sweetgum	35	
	River birch	50	
	Walnut	10	
	Southern red oak	37	
	White oak	27	
	Yellow-poplar	50	334
SEMIOPEN:	Common apple	15	
	Virginia pine	150	
	Sweetgum	165	
	Southern red oak	148	
	River birch	150	
	Gray dogwood	100	
	White oak	156	
	Persimmon	20	904
OPEN B:	Sycamore	25	
	Pin oak	28	
	Virginia pine	50	
	Yellow-poplar	25	128
OPEN C:	Green ash	100	
	Yellow-poplar	125	
	Willow oak	25	
	Persimmon	10	260
OPEN D:	Water oak	300	
	Sycamore	100	
	Green ash	200	600
OPEN E:	Yellow-poplar	50	
	Willow oak	53	
	Water oak	50	
	Sycamore	50	
	Red maple	83	
	Green ash	300	586
FIELD:	Virginia pine	50	
	Common apple	20	
	White oak	297	
	Yellow-poplar	100	
	Southern red oak	216	
	Walnut	40	
	Persimmon	20	743
			3555

TYPAR® Geotextiles

02246/TYP
BuyLine 5678

Performance That Lasts

UNPAVED ROADS	Geotextiles improve performance by providing a separation layer which prevents intermixing.
PAVED ROADS AND PARKING LOTS	Geotextiles increase the load-bearing capacity, greatly reducing the chance of premature road failure.
INDUSTRIAL YARDS AND AREAS	Geotextiles increase the life of the yard, reducing maintenance by providing superior load-supporting capabilities.
SUBSURFACE DRAINS	Geotextiles replace expensive graded aggregate filters and minimize soil piping, preventing clogged drains.
EROSION CONTROL	Geotextiles offer a fast, easy and long-lasting method to prevent soil erosion while allowing water to pass freely.
LANDFILLS	Geotextiles protect impermeable membranes from damage and drainage layers from contamination.
RECREATIONAL FACILITIES	Geotextiles prevent surface and drain contamination, allowing quick drainage for optimum use.
SEPTIC SYSTEMS	Geotextiles prolong the life of systems, preventing fine grain soil piping, while permitting the passage of septic effluent.
LANDSCAPING	Geotextiles provide excellent soil retention and weed control in landscape applications.

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a member of The InterTech Group, Inc.

TYPAR® - The ideal geotextile

A nonwoven permeable separator for roads, drainage systems, erosion control and landfills

Tough, durable, thermally spunbonded polypropylene fabric separates subgrade soil from aggregate base, and lets water pass through.

No matter what your needs, Typar geotextiles offer a fast, economical and proven alternative to more traditional and expensive construction methods.

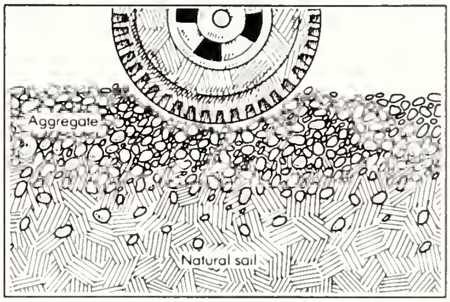
Tough, durable Typar offers a number of benefits:

- Prevents aggregate from intermixing with soil
- Prevents base deterioration under roads, parking lots and industrial areas
- Prevents clogging of drainage systems
- Prevents soil movement in erosion control applications
- Protects geomembranes and drainage layers in landfills

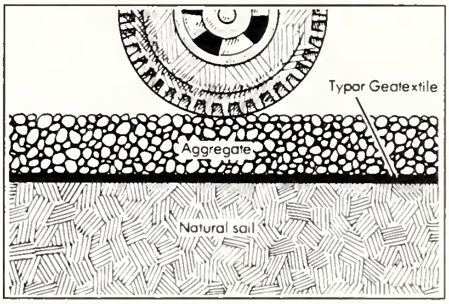
Typar Geotextiles - the permeable separator that lasts!

TYPAR GEOTEXTILE APPLICATIONS

Unpaved and Paved Roads, Parking Lots and Industrial Yards & Areas. Typar geotextiles provide a rugged separation layer between aggregate and subgrade in roads, parking lots and industrial yards. Without this separation layer, aggregate and soil can intermix, leading to the progressive deterioration and eventual failure of the structure. In addition to paved roads and parking lots, Typar can be used for access roads; mining, quarry and logging haul roads; temporary construction roads for residential and commercial developments; low-volume rural roads; railroad and truck freight yards; and log and ore storage areas. Typar geotextiles save time and money during construction by reducing the required site preparation and aggregate base thickness as well as labor and equipment costs. And by solving the problem of base deterioration, Typar improves performance, increases the service life of the road or yard, and reduces long-term maintenance costs.



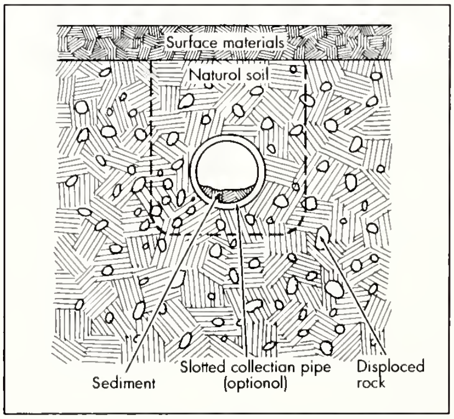
Without Typar, soil contaminates and weakens aggregate base producing failure of the road.



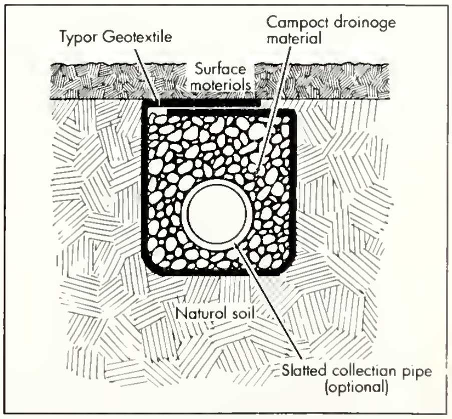
With Typar, aggregate won't sink into and intermix with subsoil.

Drainage and Septic Systems

Subsurface drains require a properly designed protective layer that prevents the intrusion of native soil into a drain and clogging of the drainage system. Septic systems disperse liquids by percolation into the ground through drainage fields, a function which requires a permeable separation layer. Typar geotextiles offer a proven alternative to graded aggregate or sand filters, which are difficult to install properly and are more expensive than Typar. Because of their permeability, strength, and chemical resistance, Typar geotextiles permit faster, simpler construction; eliminate the need for drain pipes in some cases; prevent soil intrusion and the potential for clogging; and prolong the life of septic drain fields. Typar's track record as a separator in thousands of subsurface drainage projects (edge-of-pavement, interceptor, subsurface structure and blanket drains) and septic systems means that you can specify them with confidence.



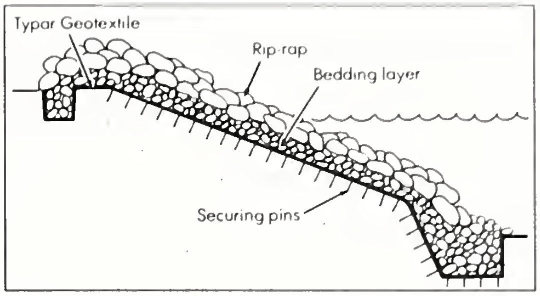
As soil particles infiltrate the slotted pipe or aggregate trench, they reduce the capacity of the drainage system.



Typar separates soil from the drainage material.

Erosion Control

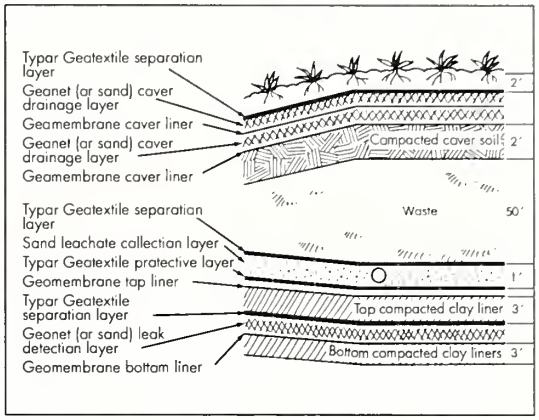
Typar geotextiles offer a proven alternative to graded aggregate or sand filters for use in erosion control structures for protection of stream banks, shorelines, slopes, submerged foundations, retaining walls and bulkheads and revetments. Erosion protection structures dissipate the hydraulic forces that cause erosion and contain the natural or fill soil behind them, preventing piping or erosion of natural soil. Installation of Typar with a layer of heavy stone, broken rock (rip-rap), gabions or pre-cast blocks is fast, easy and cost-effective, saving construction time and money over traditional methods. Typar is ideally suited to erosion control applications due to its strength; permeability (allowing efficient drainage); durability; ease of installation; conformability; and resistance to rot, mildew and chemicals.



Shoreline erosion control.

Landfills

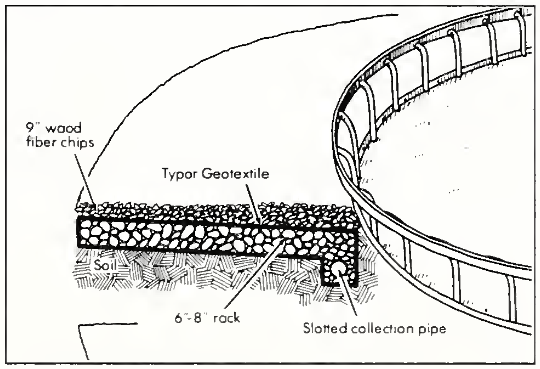
Typar geotextiles serve important functions in all types of landfill and waste management applications, from simple municipal landfills to sophisticated hazardous waste landfills. They can be used in municipal waste landfills as a protective layer to prevent geomembrane liner damage; as a permeable separation layer to preserve drainage layers; to prevent clay from pushing into geonet drainage layers; and in cover systems at municipal waste landfills as separation and protective layers. Because Typar resists a wide range of chemicals, it is frequently used in hazardous waste landfills which must meet stringent EPA regulations. Typar is economical to use; permits fast and simple construction; meets strict FHWA drainage criteria for most applications; has high tensile strength and puncture resistance; resists attack by most chemicals; and is very permeable, tough and durable.



Typical EPA landfill.

Recreational Facilities

Facilities such as football fields, baseball diamonds, tennis courts, soccer fields, swimming pools, horse & dog tracks, walking trails and golf course sand traps and greens require both subgrade drainage systems and a separation layer to prevent surface contamination and provide fast, adequate drainage. Blanket and trench drain systems for recreational facilities often use Typar as a permeable separator. Typar geotextiles are economical; permit faster, simpler construction; eliminate the need for a drain pipe in some cases; minimize soil piping and the potential for drain clogging; preserve the integrity of specialized surface materials; significantly reduce ongoing maintenance; and eliminate the need for sacrificial material when required in the various layers of the structure.

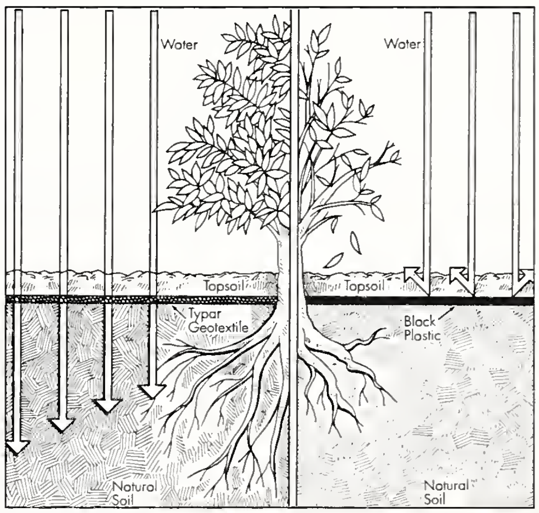


Blanket drain application for recreational facilities.

Landscaping

Typar is ideally suited for landscape applications: its permeability allows for quick drainage; it prevents piping or erosion of subgrade soils; it is tough, strong, conformable, and durable; and most vegetation cannot penetrate through the surface of Typar. Generally, Typar is placed between the natural soil and either stone chips, timber, brick or concrete block, and in landscaped beds. Typar geotextiles can be used for weed control in landscaped beds or under decks; for soil retention behind timber retaining walls, blind drains, planters and pots; and as support to prevent cracking or uneven settling in brick or block patios and walks.

Compared to the plastic film on the right, Typar's porous structure allows water and air to pass through to plant roots.



Typar Nonwoven Geotextiles Physical Properties And Applications (Minimum Roll Average Values)

Properties	**Test Method**	**TYPAR 3151**	**TYPAR 3201**	**TYPAR 3301**	**TYPAR 3341**	**TYPAR 3401**	**TYPAR 3601**
Unit Weight (oz/yd^2)	ASTM D-3776	1.5	1.8	2.9	3.3	3.9	5.8
Grab Tensile (lbs)	ASTM D-4632	35	60	120	120	130	200
Elongation at Break (%)	ASTM D-4632	60	60	60	60	60	60
Modulus at 10% Elongation (lbs)	ASTM D-4632	175	300	600	600	650	1000
Trap Tear (lbs)	ASTM D-4533	15	25	30	40	60	75
Mullen Burst Strength (psi)	ASTM D-3786	50	65	90	90	140	210
Puncture Strength (lbs)	ASTM D-4833	10	18	25	30	40	60
A.O.S. (Equivalent Sieve)	ASTM D-4751	20	30	50	60	70	140
(mm)		0.84	0.59	0.30	0.25	0.21	0.10
Flux (gal/ft^2/min)	ASTM D-4491	235*	200*	100*	85*	60*	25*
Permittivity (sec^{-1})	ASTM D-4491	0.5	0.5	0.3	0.3	0.1	0.1
Coefficient of Permeability (x10^{-2} cm/sec)	ASTM D-4491	0.03	0.03	0.02	0.02	0.01	0.01
Accelerated Weathering Strength Retained after 500 hrs (%)	ASTM D-4355	—	—	—	70	80	90
Applications							
Unpaved Roads					■	■	■
Paved Roads & Parking Lots					■	■	■
Industrial Yards & Areas					■	■	■
Subsurface Drains			■	■	■	■	
Erosion Control					■	■	■
Landfills					■	■	■
Recreational Facilities			■	■	■	■	
Septic Systems		■	■	■	■		
Landscaping			■	■			
Packaging		**TYPAR 3151**	**TYPAR 3201**	**TYPAR 3301**	**TYPAR 3341**	**TYPAR 3401**	**TYPAR 3601**
Roll width (in.)		60 151	36 48 75 151	36 48 75 151	151	151 197	151 187
Roll length (lin. yd.)		100	100	100	100	100	100
Roll diameter (in.)		7	7	8	8	9	10
Gross weight/roll (lbs)		19 50	14 18 28 58	21 28 44 87	97	113 150	165 205
Square yards/roll		167 419	100 133 208 419	100 133 208 419	419	419 547	419 519

*typical value

*The facts stated and the recommendations made herein based on our research and the research of others are offered free of charge and are believed to be accurate. No guarantee of their accuracy is made, however, and the products discussed are distributed without warranty, expressed or implied, and upon condition that recipients shall make their own tests to determine the suitability of such products for their particular purposes. Likewise statements concerning the possible uses of our product are not intended as a recommendation to use it in the infringement of any patent, whether owned by Reemay, Inc. or others.

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T-89001

EROSION CONTROL AND REVEGETATION

VERDYOL ERO-MAT

VERDYOL EXCELSIOR

Stitched Erosion Control Degradable Mats

- provides ideal growth conditions
- encourages easy germination of grasses
- retains moisture
- prevents soil loss
- cost effective
- easy installation

Natural products for hydraulic seeding

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EROSION CONTROL DEGRADABLE MATS

verdyol ERO-MAT verdyol EXCELSIOR

Verdyol stitched blankets are machine assembled. The primary components of VERDYOL ERO-MAT are clean wheat fibers processed from agricultural crops. VERDYOL EXCELSIOR is made out of fibers processed from hardwood. The fibers are evenly distributed throughout the blankets to a loose thickness of approximately 3/8".

The top sides of both blankets (STD & HV) are covered with an extruded degradable polypropylene (PP) netting and is adhered to the fibers by a stitching process using a strong degradable thread. The bottom sides of the High Velocity blankets are also covered with degradable polypropylene netting.

Specifications:	VERDYOL ERO-MAT Standard	VERDYOL ERO-MAT High Velocity	VERDYOL EXCELSIOR Standard	VERDYOL EXCELSIOR High Velocity
Material	100% Straw	100% Straw	100% Wood Fiber	100% Wood Fiber
Thickness (in.)	3/8"	1/2"	3/8"	1/2"
Weight (lbs./sq.yd.)	.55	.58	.85	1.1
Average Fiber Length (in.)	7"	7"	12"	12"
Number of nets	1	2	1	2
Opening Size of the Top Netting	3/4" x 3/4"	3/4" x 3/4"	3/4" x 3/4"	3/4" x 3/4"
Opening Size of the Bottom Netting		3/4" x 3/4"		3/4" x 3/4"
Dimensions per roll: (± 5%)				
length (ft.)	120'	120'	96'	60'
* width (ft.)	7 1/2'	7 1/2'	7 1/2'	7 1/2'
area (sq.yd.)	100	100	80	50
weight (lbs.)	55	58	68	55
package	PP Bags	PP Bags	PP Netting	PP Netting
Suggested Application:	Slopes, Low Flow Ditches	Ditches, Steep Slopes	Slopes, Low Flow Ditches	Ditches, Steep Slopes

* Available in 6 1/2' width.

NATURAL HYDRAULIC SEEDING PRODUCTS

verdyol MULCH

Use:
- control of erosion
- seed protection
- ground cover
- soil improvement

Specifications: straw fiber length approx. 1/4"
moisture content: 7 - 8%
pH range: 6.5 (± 1.0)
ash content: 2.3%

Components: 50% wheat straw, 50% recycled paper*

Recommended dosage: 1200-1500 lbs. per acre

Package: bales of 3.75 cu. ft. in polypropylene bags (approx. 50 lbs.)

verdyol SUPER

Use:
- erosion control
- dust binding and soil stabilization
- adhesion of seeds and mulch
- soil stabilization without seeding

Specifications: water-soluble brown powder
density 0.7
pH range 7.3
does not seal the soil surface

Components: polymerised, organic substances, derived from oceanic and land vegetation.

Tolerability: VERDYOL SUPER is a natural product meeting environmental requirements

Recommended dosage: 80 - 120 lbs. per acre

Package: bags of 20 lbs.

* Available with organic soil stabilizer - mulch binder and environmental safe green coloring.

Verdyol Alabama, Inc. is an affiliated company of Verdyol International, A.G., Switzerland. Operation began in 1987 at the the Pell City location.

The company manufactures erosion control and soil reinforcement blankets as well as natural products for hydraulic seeding and environmental care.

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Pell City, AL 35125
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Fax: 205-338-4595